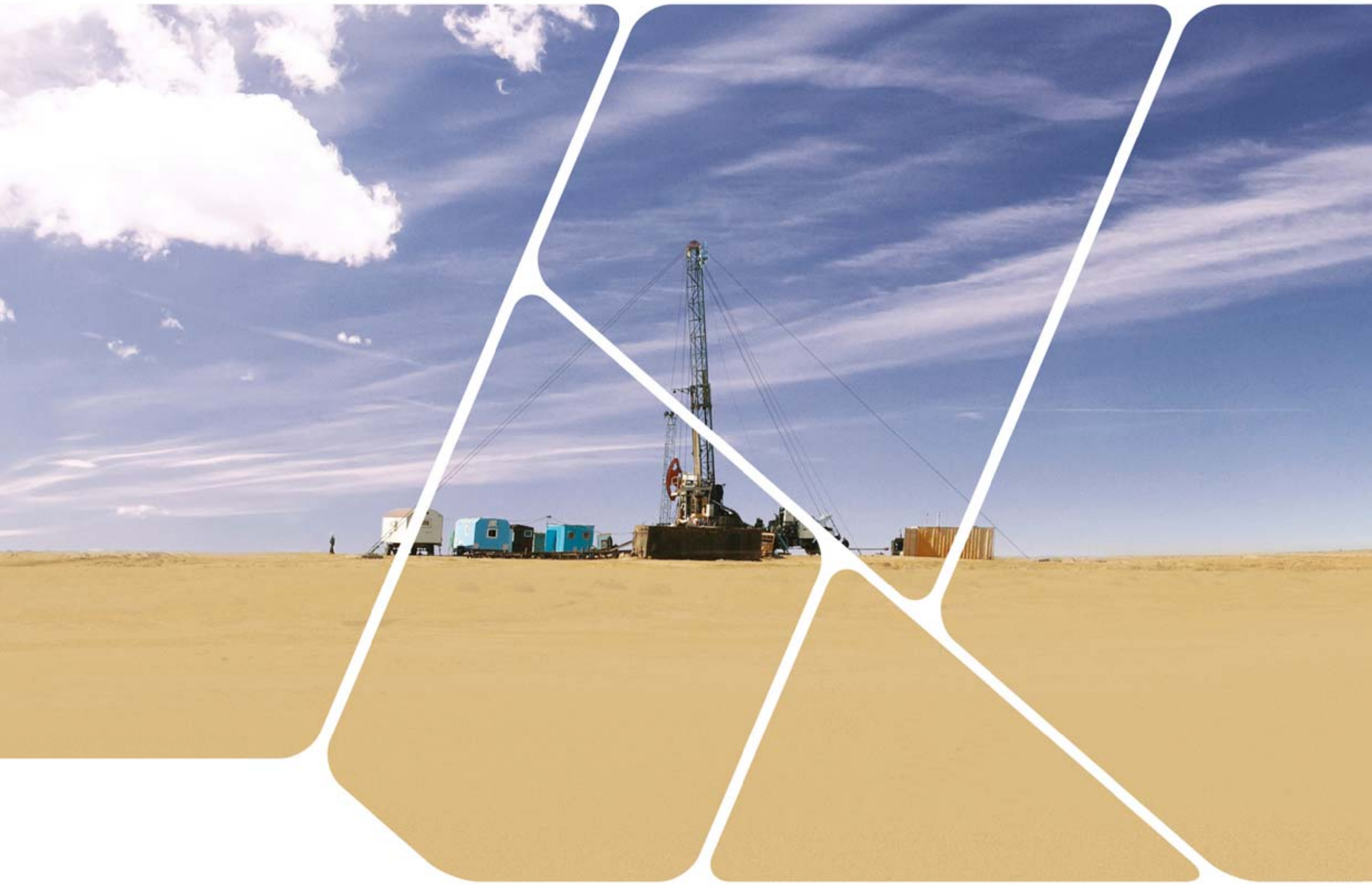


RESERVOIR ENGINEERING GRADUATE CERTIFICATE - *Week 4*

Reservoir Characterization & modeling - Workshop PETREL

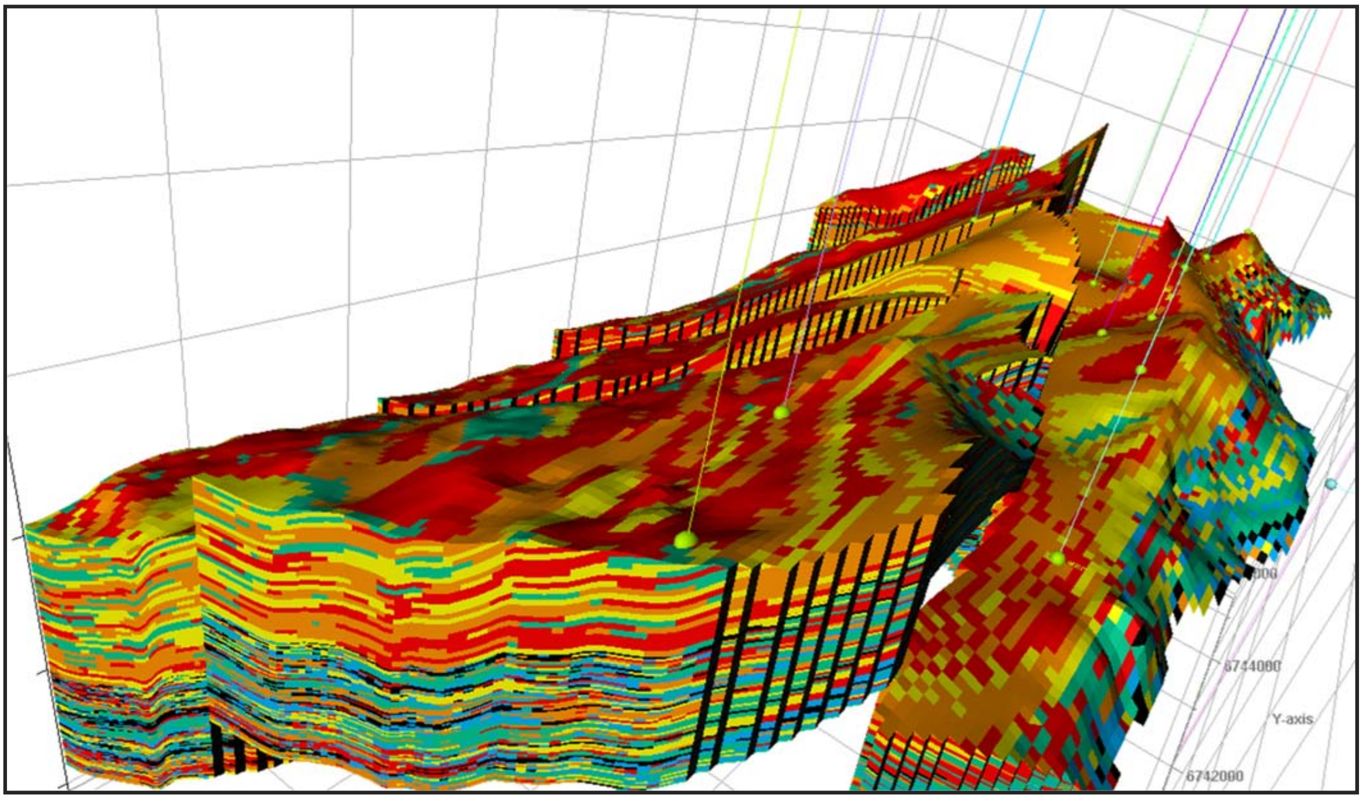
A special course by IFP Training for REPSOL ALGERIA
Alger – November 20 - 24, 2016

Alwyn field case study

Reservoir Characterization & Modeling workshop

Instructor : Aissa BACHIR

IFP Training



Confidentiality

- Created and developed by and for IFP Training
- These data and this document are confidential, used in a conventional context, for educational purposes only and they cannot be shown outside IFP Training's sessions.
- The databank used in the case studies was extracted from real field cases.
- For educational matters, the model built with this data subset is a simplified one, but calls for the same methods and workflow as for the complete study.
- The results cannot be the same as in the real case.
- These data are used to illustrate reservoir characterization and modeling workflow steps. They were made up (both coordinates and depths were changed) to meet educational purposes.
- These data were given under a non-disclosure agreement between the participant's company and IFP Training.

Software tools

- **Modeling:**
  - *Petrel©* 2015.2
- **Rock typing:**
  - *EasyTrace©* 2015.2

Alwyn field case study - Summary

Alwyn field case study - Summary

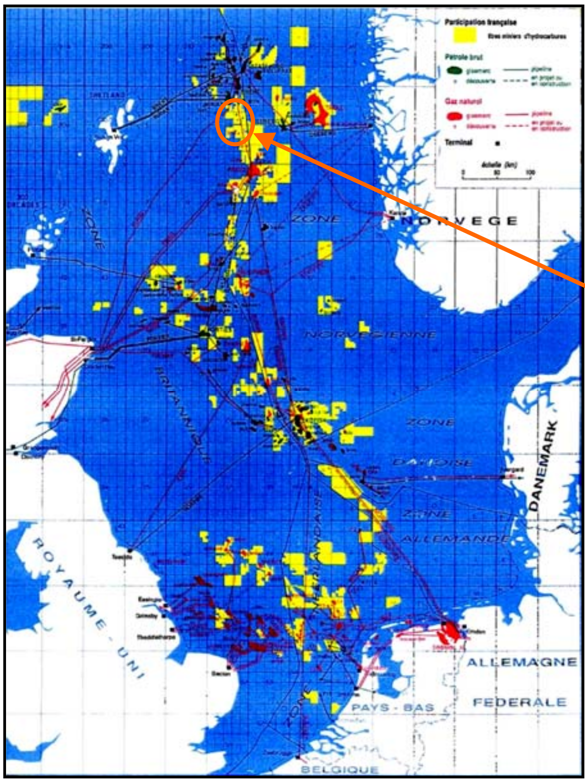
1. Introduction

General context and geological setting

Location map

- **Alwyn field location**
  - East of Shetland islands
  - West of Norway

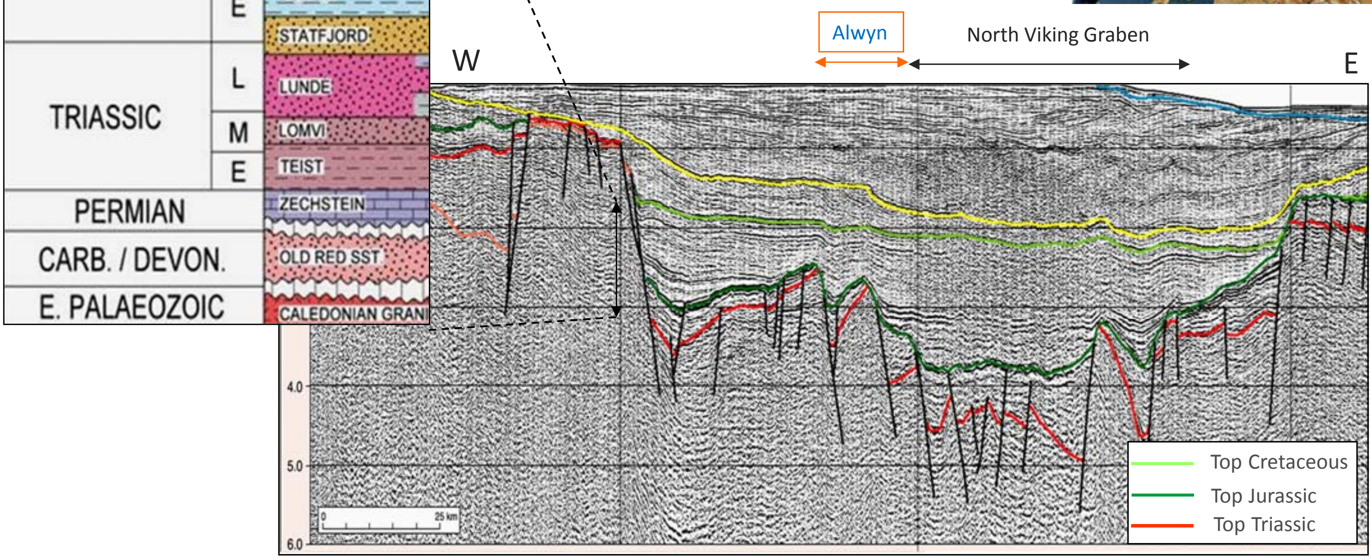
North sea license blocks



Map of the British mining licenses

- **Block 3/9 location**
  - East of Shetland islands
  - West of Norway
- **Joint venture partners**
  - TOTAL OIL MARINE (operator)
  - ELF UK (partner)

Regional lithostratigraphy



Alwyn field E&P story

- **Exploration**
  - 1965: Lease granted to Elf/Total (offshore UK)
  - 1972-1973: First shows
  - 1975: Discovery on block 3/9 (well 3/9 A6)
    - Oil in Brent
    - Gas in Statfjord
  - 1976: Confirmation by 4 other wells
  - 1979-1980: 2D seismic acquisition
  - 1980: 3D seismic acquisition
  - 1982: Reserves evaluation
  - 29 Oct. 1982: Agreement from UK Government

- **Development**
  - 1983: Development start
  - 1985: “First oil” (production start)
  - 1996: New 3D seismic acquisition
  - 2009: Production ≈ 130,000 bpd of oil
  - 2013: Still producing

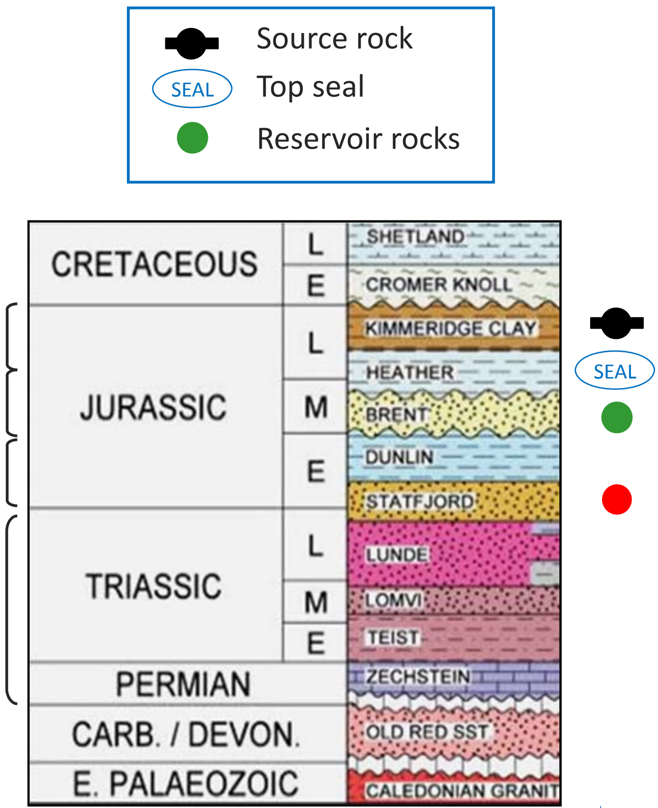
Geological history & Petroleum system

- **Mid Jurassic: New extensional phase**
  - Fault reactivation
  - Brent fm deposition
- **Upper-Jurassic:**
  - Callovo-Oxfordian: tectonic activity increase
    - Faulted block tilting
    - Heather fm deposition (syn-rift)

➔ **Main seal of petroleum system**
  - Kimmeridgian: Callovian tectonic continuation
    - Kimmeridge clay deposition (syn-rift)

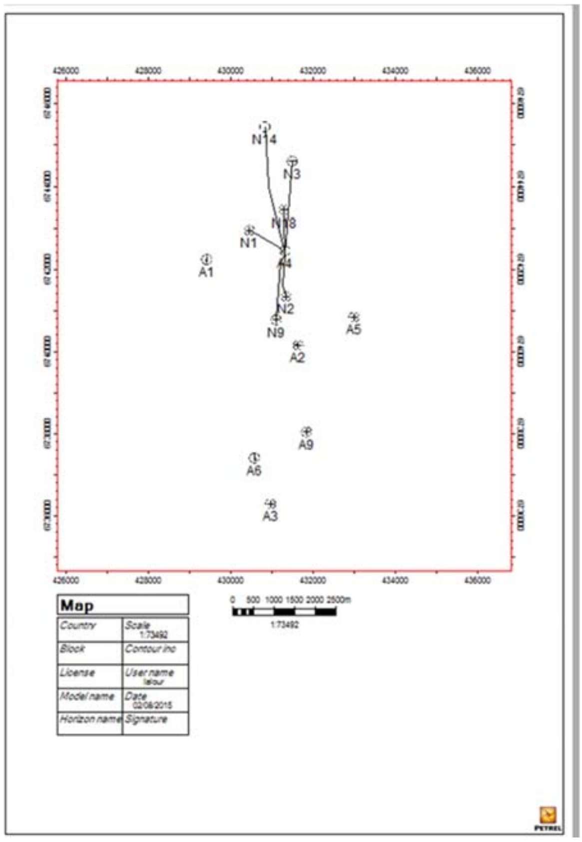
➔ **Main source rock of North sea fields**

- **Lower Jurassic: Quiet tectonic**
  - Dunlin shale deposition
- **Permo-Triassic: West-East extension**
  - N-S and W-E faulting
  - Eastward basin subsidence
  - Statfjord fm deposition



Location map

- **13 wells with available data**
  - 7 exploration wells
    - **A1 - A2 - A3 - A4 - A5 - A6 - A9**
    - All logged
  - 6 development wells
    - **N1 - N2 - N3 - N9 - N14 - N18**
    - All cored and logged
  - Core images on well N_2
- **2D seismic lines**



→ Continue with Petrel…

2. From field to grid

Chapter 2 - Summary

From field to grid *(Petrel©)*

- *Petrel©* modeling toolbox - [2A]
  - Getting started with *Petrel©*
- Project data loading - [2B]
  - Best advices
  - Data loading
- Alwyn static model architecture - [2C]
  - Structural characterization
  - Structural modeling
  - Stratigraphic characterization
  - Stratigraphic modeling

Petrel© working environment

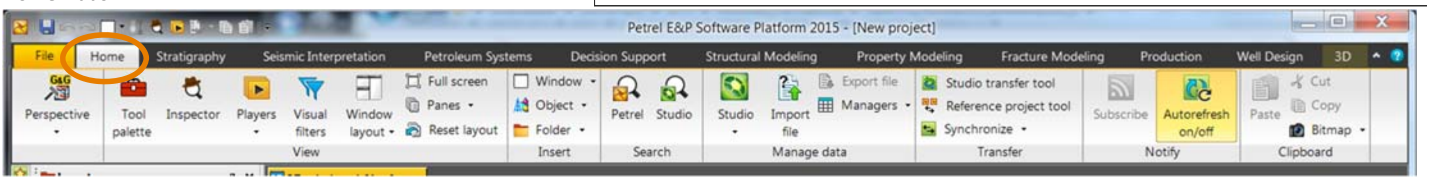
Open "Empty frame" project

Part 2A

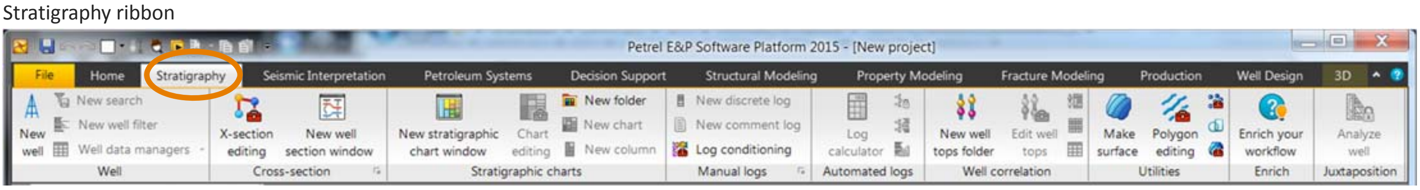
The contextual Ribbon interface

Tools and process for each step (Stratigraphy/Structural modeling Property modeling…)

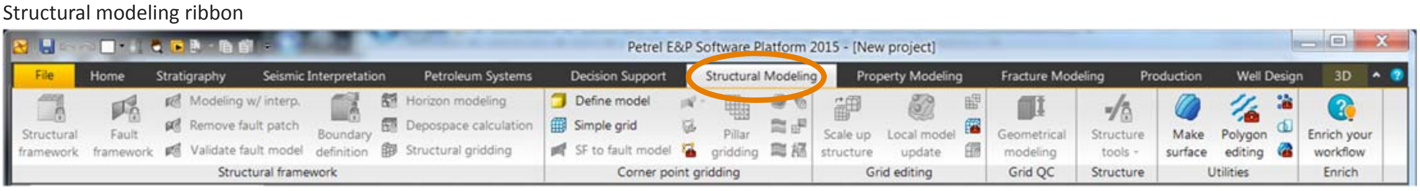
Home ribbon



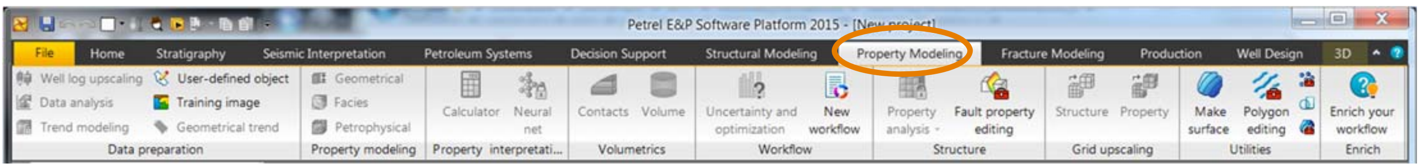
Stratigraphy ribbon



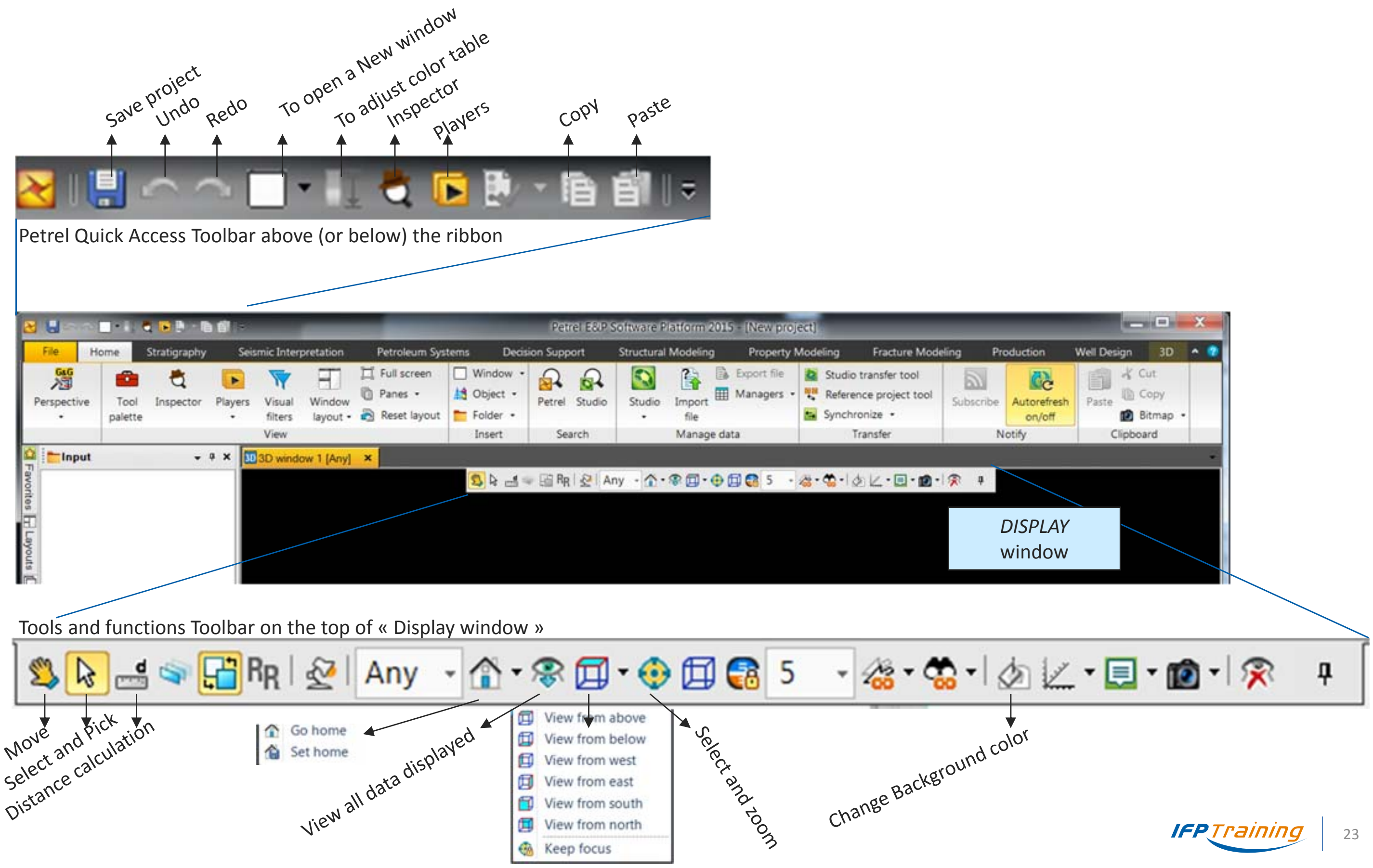
Structural modeling ribbon



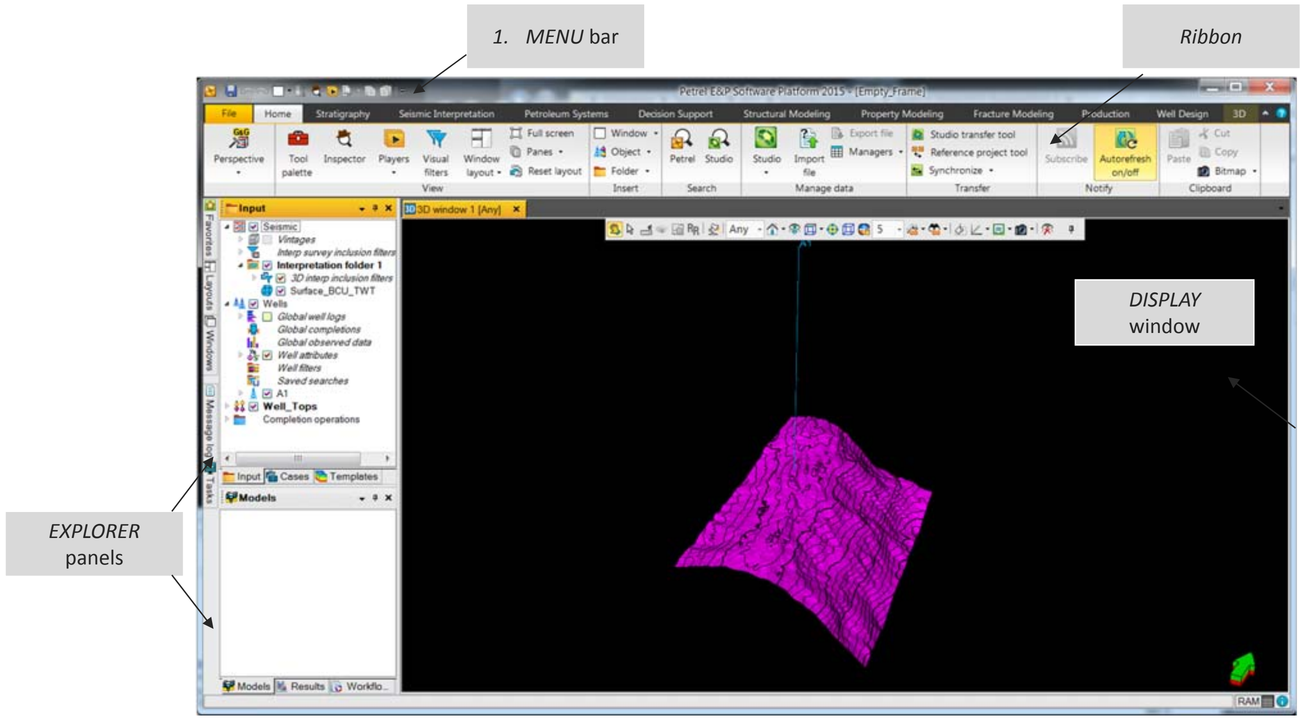
Property modeling ribbon



Most used icons



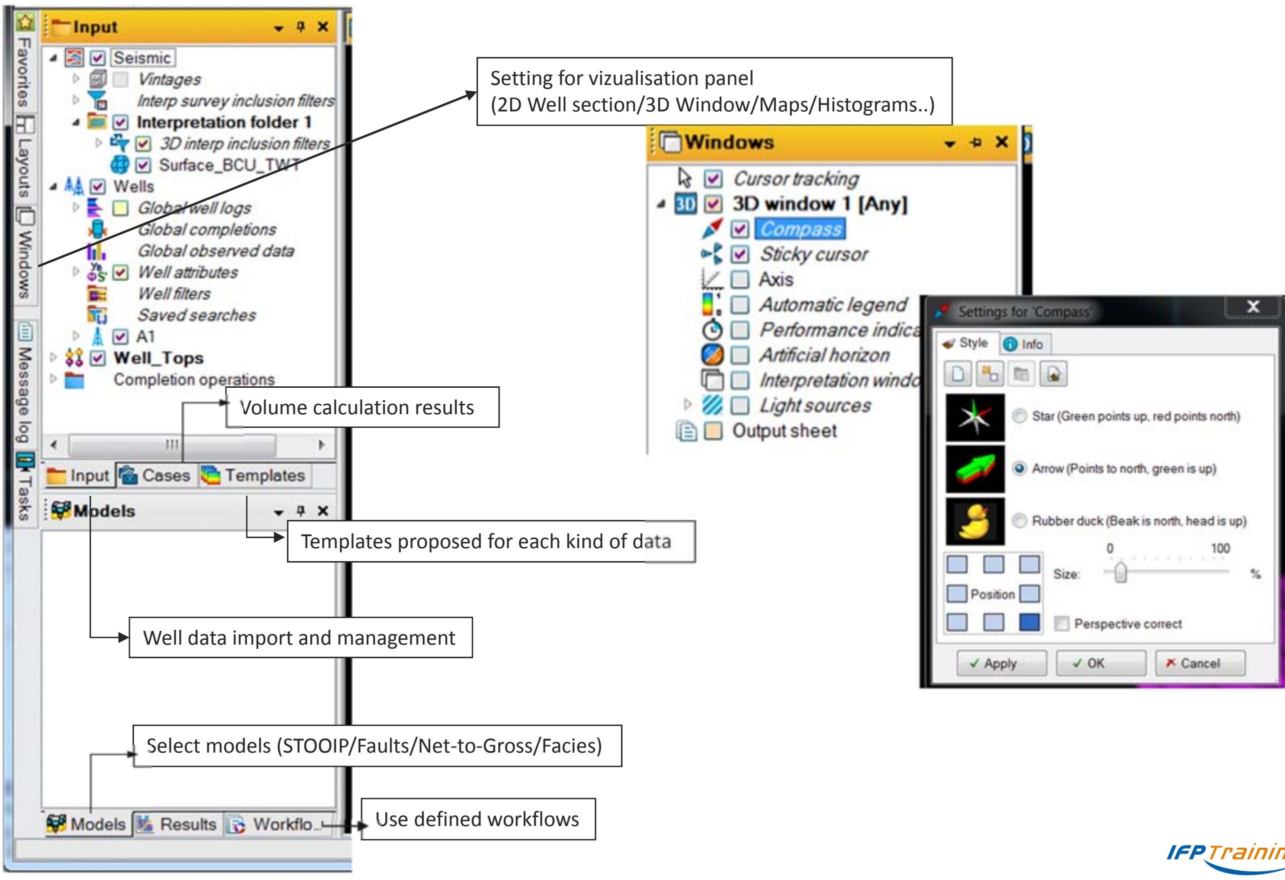
Interface set up



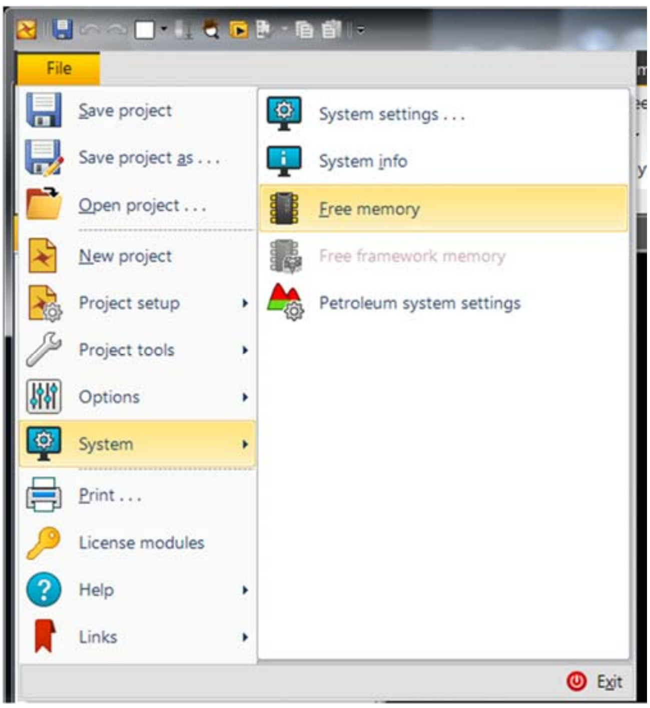

pkey = arrow (pick)

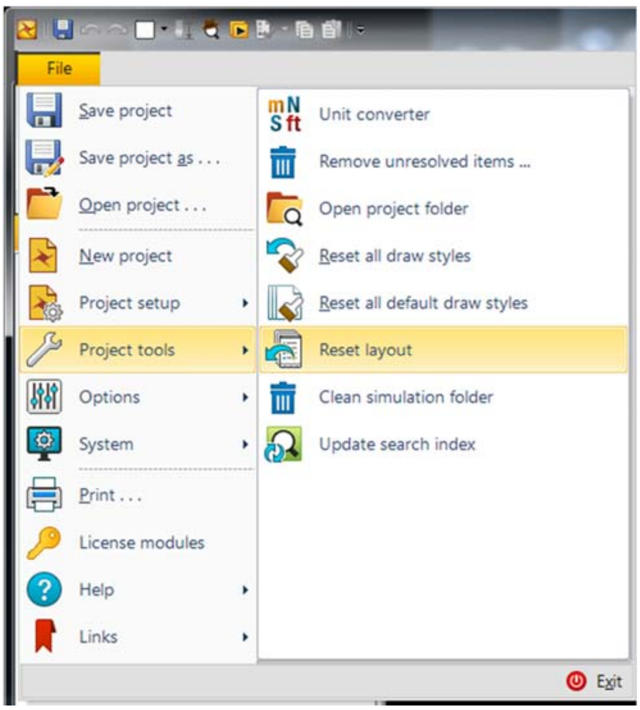

vkey = hand (view)

Explorer panel



Tips

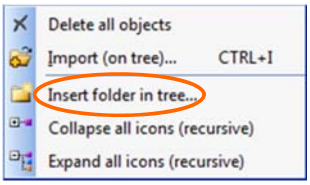




Warning: prevent Petrel from crashing!
File → "System" → "Free memory"

To re-organize all the windows
File → "Project tools" → "Reset layout"

- **Manage data the same way as on Windows explorer**
- **To insert folder in tree**
  - Right click in the input window
  - Select "Insert folder in tree…"
  - Rename it
  - Drag and drop data



Rename folder: Press F2 key
Use button to get help

Getting started with Petrel©

Part 2B

Summary

- Best advice and useful tips
- Project data loading
- Data QC

Best advice and useful tips

- **Classify uploaded data (“.las”, “.ascii”, “.dev”…) in a “databank” folder; close the “model” folder**
  - Optimize data loading
  - Back-up in case of problem
- **Save the intermediate model at each modeling step**
  - Helps for reporting and for presentations
  - Write a short document to explain each step of the upgraded model
  - Good tool for the team: improves workflow understanding
- **Use tutorial videos to visualize the adequate manipulations and to better understand the workflow sequencing**

Project data loading

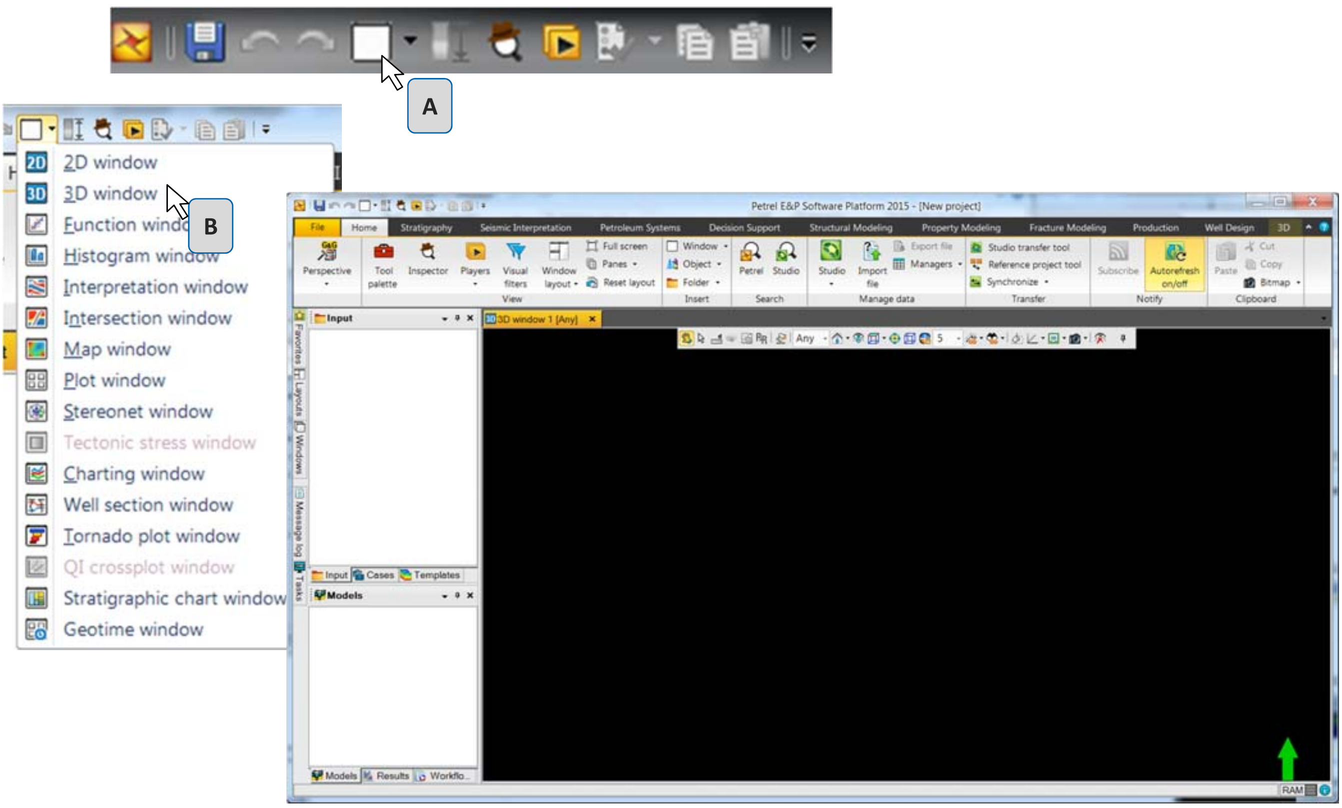
Inventory of available data

- **Format ZGY**
  - Seismic data
- **Format Ascii**
  - Surfaces from seismic (interpreted)
    - BCU
    - Dunlin
  - Polygons
    - Boundaries
      - BCU
      - Dunlin
    - Faults
  - Well data
    - Headers, deviations, logs, tops

Data import steps

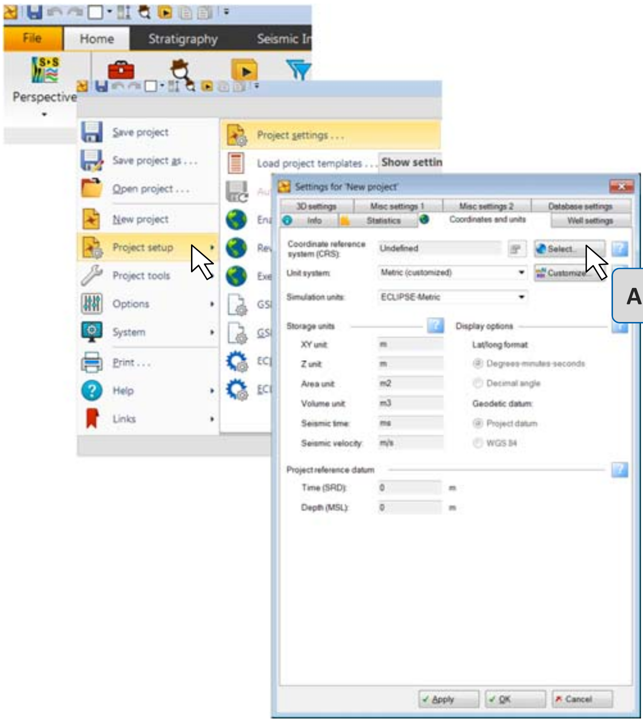
1. New Project
2. Coordinates and projection system
3. Seismic data
   - 2D lines
4. Well headers
5. Well trajectories (deviation paths)
6. Well tops
7. Well logs
8. Fault sticks
9. Fault polygons
10. Boundary polygons
11. TWT grid points

In a new project - Open a 3D window



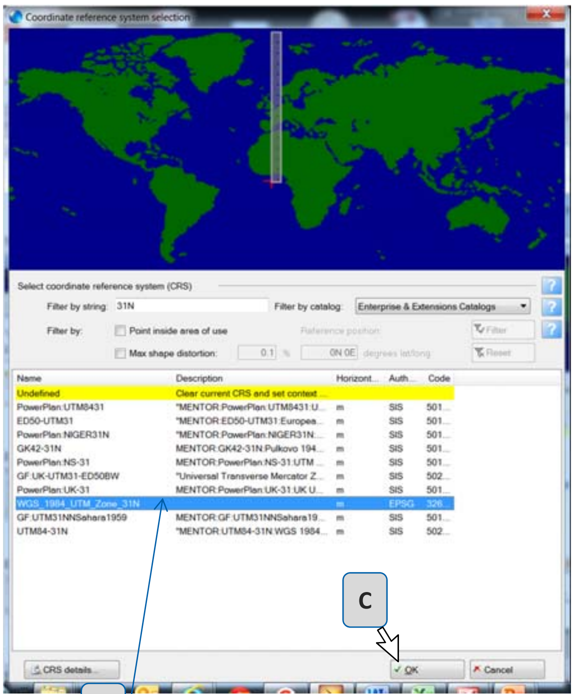
Coordinates and projection system

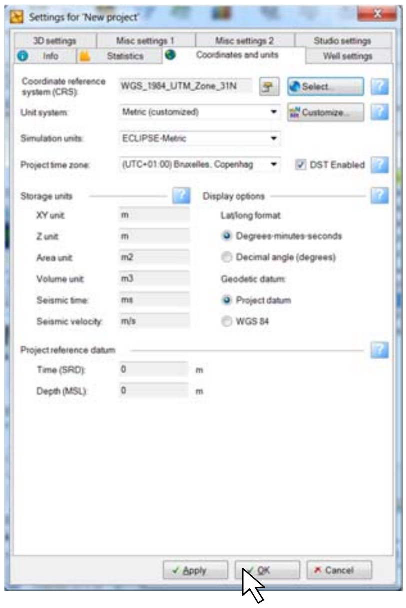
- Select → File → Project Setup → Project Settings
- *Click on the button "Select" (A)*



Coordinates and projection system

- In the filter write "31N" (A)
- Select WGS_1984_UTM_Zone_31N
- OK (C)

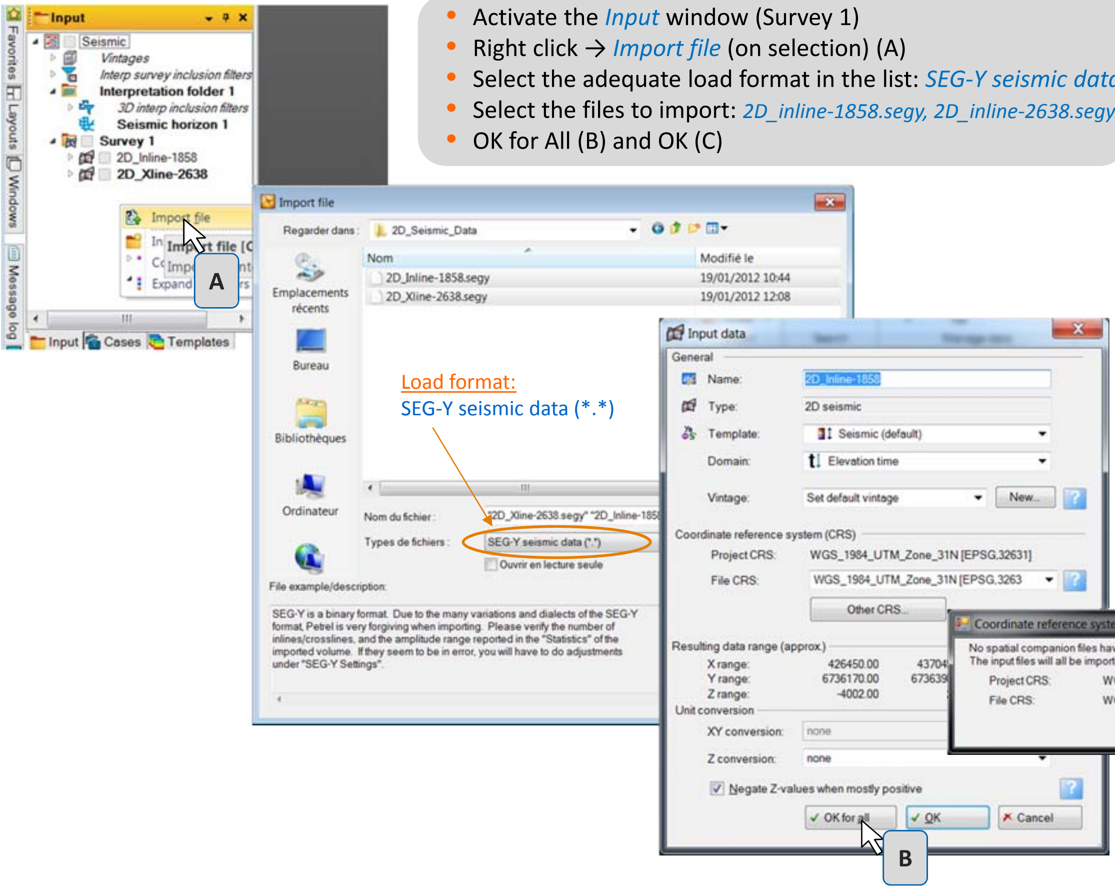


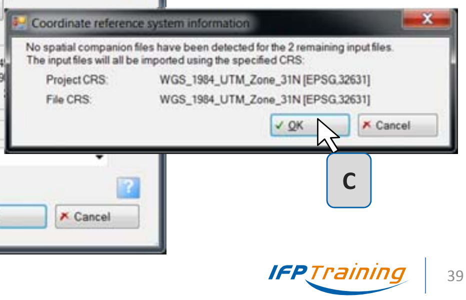


WGS_1984_UTM_Zone_31N

2D seismic data from SEG-Y file - *Seismic profiles*

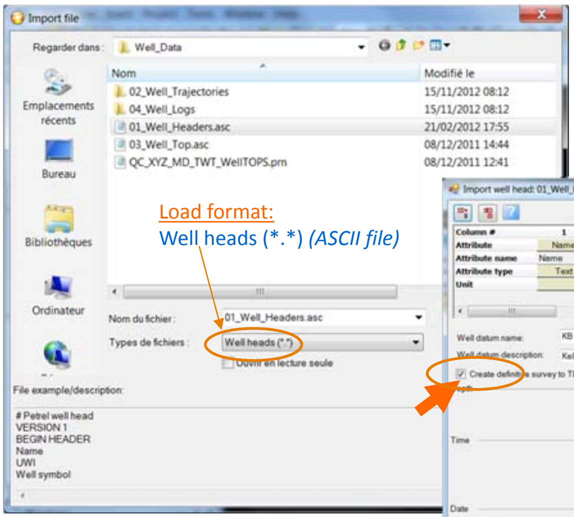
- Activate the *Input* window (Survey 1)
- Right click → *Import file* (on selection) (A)
- Select the adequate load format in the list: *SEG-Y seismic data*
- Select the files to import: *2D_inline-1858.segy, 2D_inline-2638.segy*
- OK for All (B) and OK (C)

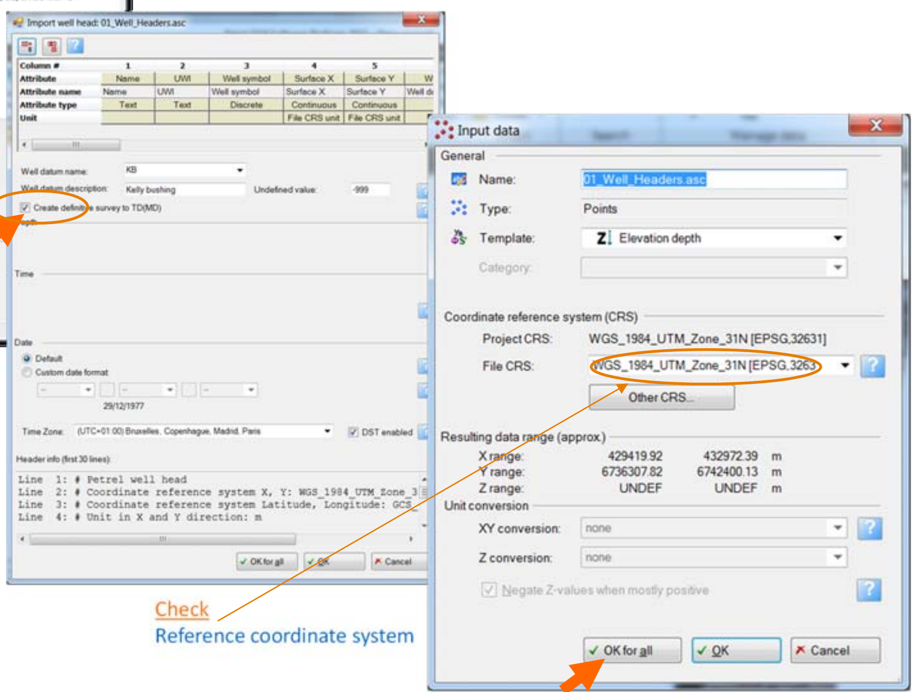


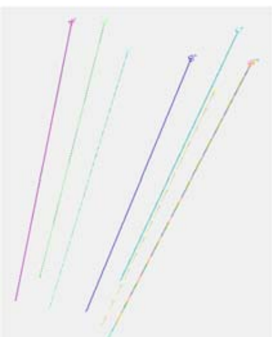


Well data from *ascii* file - *Well headers*

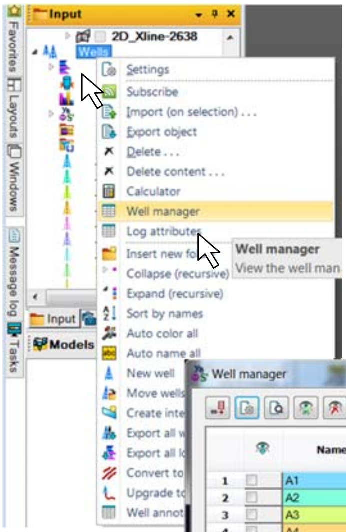
- Activate the *Input* window
- Right click → *Import file*
- Select the adequate load format in the list: *Well heads*
- Select the file to import: *01_Well_Headers.asc*



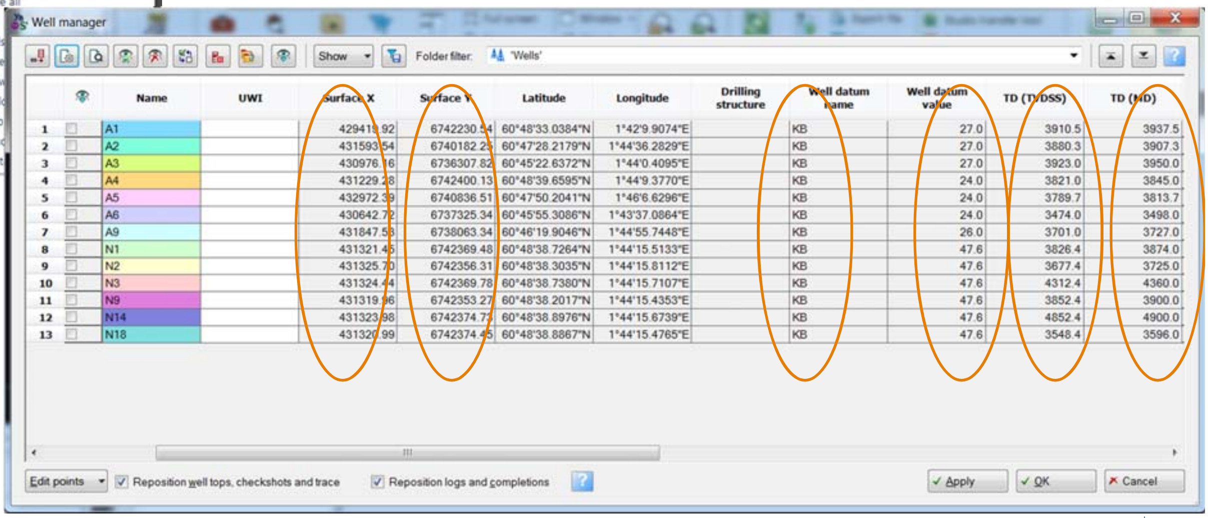




Well heads – Quality control

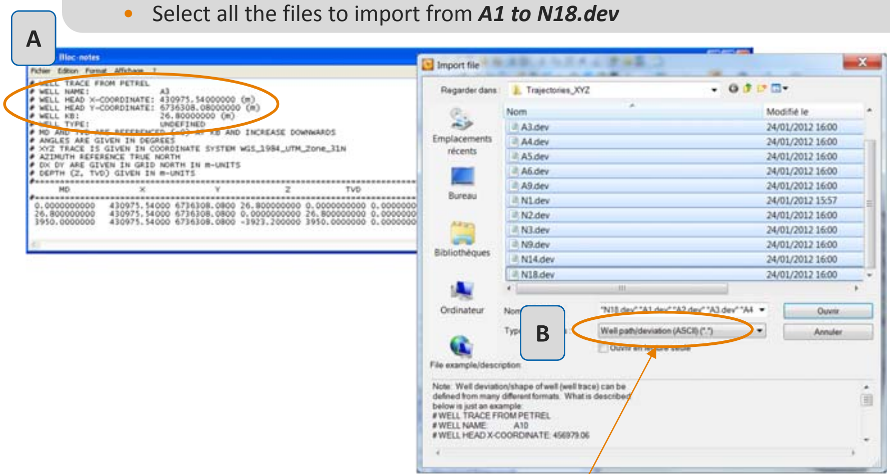


- **In Petrel software, Offset stands for KB**
  - Right click on the “well” icon in the “Input” window
  - Open the “Well manager” to QC the import
  - Check X, Y and Well datum value (= KB) and TD (MD) columns



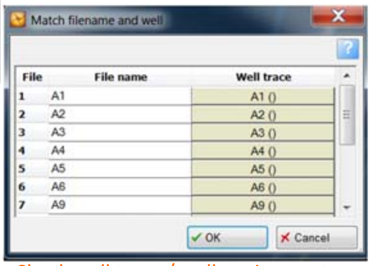
Well data from *ascii* file - *Well trajectories*

- **Well trajectory**
  - Edit one of the *ascii* files to import (with text editor) to check format - (A)
  - Select *Import file*. Select the file format in the list: *Well path/deviation (ASCII)* - (B)
  - Select all the files to import from ***A1 to N18.dev***



Load format:
Well path/deviation (ASCII) (*.*)

→



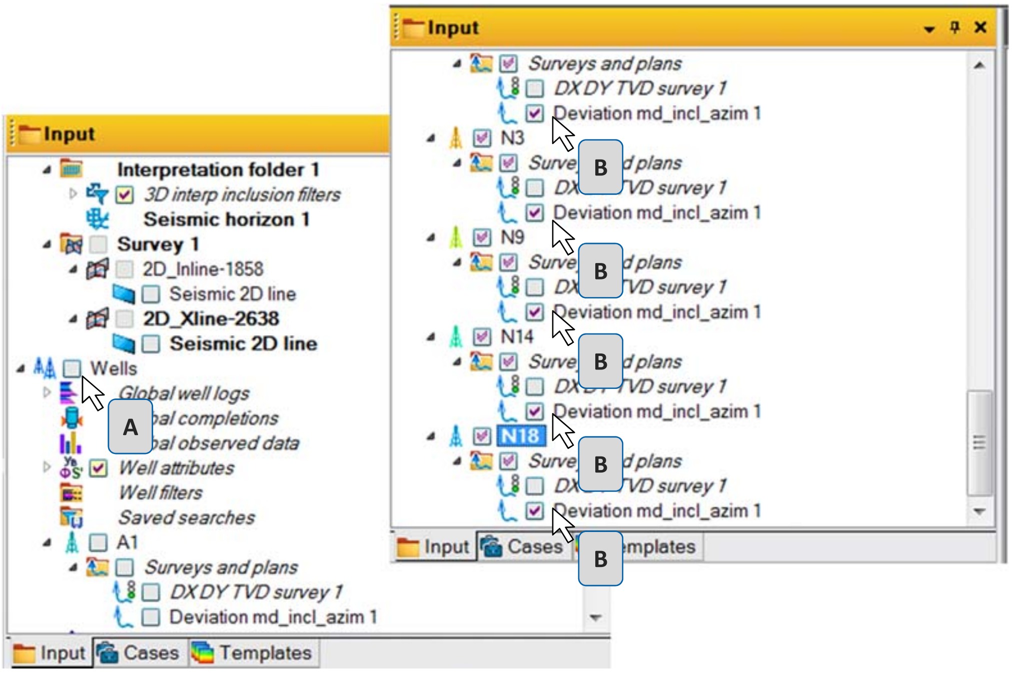
Check well trace / well assignment

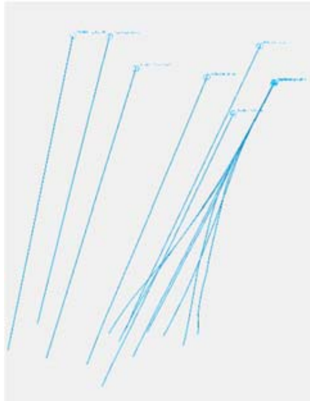
As headers are loaded, choose “MD/INCL/AZIM”
If no header, use “X/Y/Z”

Note that well head coordinates are given in the header.

Well data from *ascii* file - *Well trajectories*

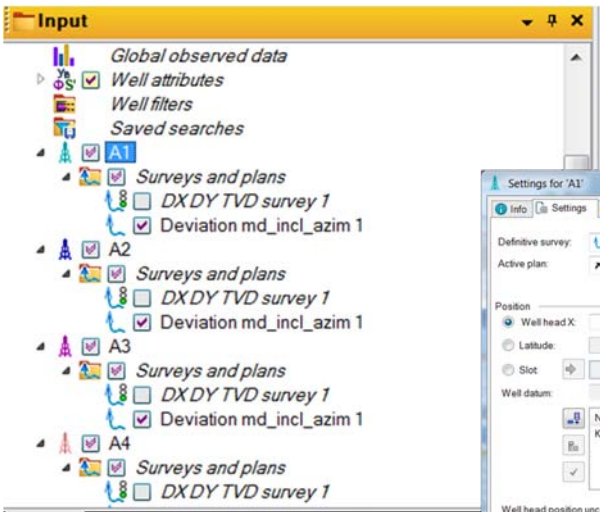
- **Well trajectory**
  - Unselect Wells (A)
  - *Select "Deviation md_incl_azim 1" for each well (B)*

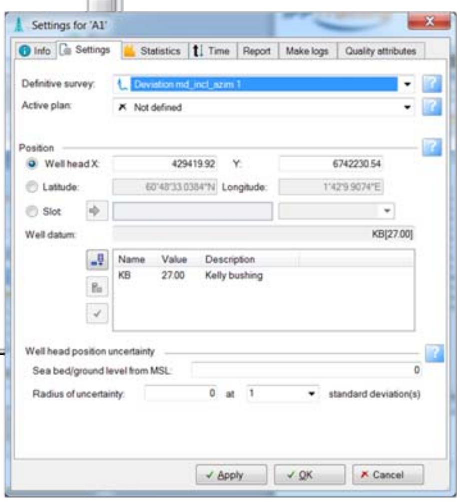




Well data from *ascii* file - *Well trajectories*

- **Choose well trajectory**
  - Select the first well and right click on "Settings" (A)
  - *Choose Definitive survey "Deviation md_incl_azim 1" and apply (B)*
  - *Redo for each well or use the short cut on next slide*

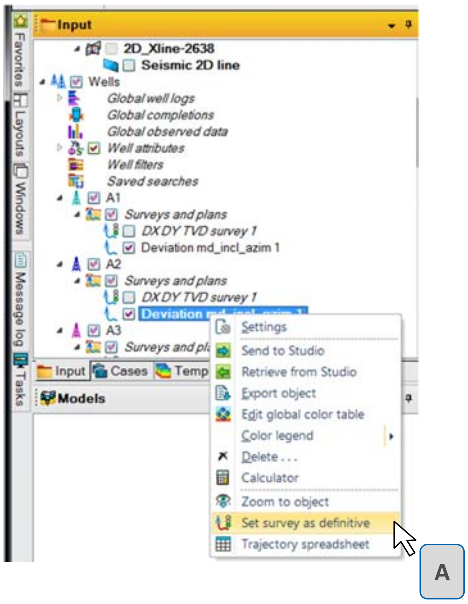


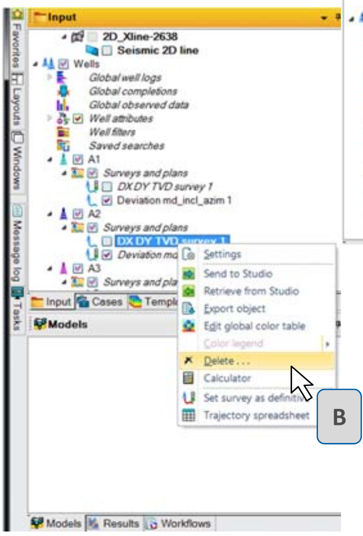


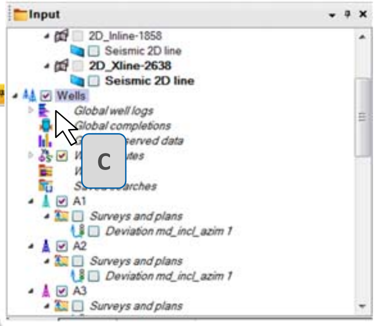
Multiple trajectory can be managed for the same well.

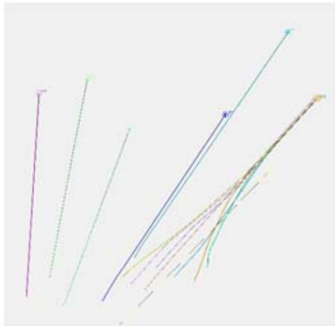
Well data from *ascii* file - *Well trajectories*

- **Choose and clean well trajectories**
  - Right click on the well trajectory to assign as definitive trajectory (A)
  - Delete the other trajectory (B)
  - Select the well to display it with the good trajectory (C)

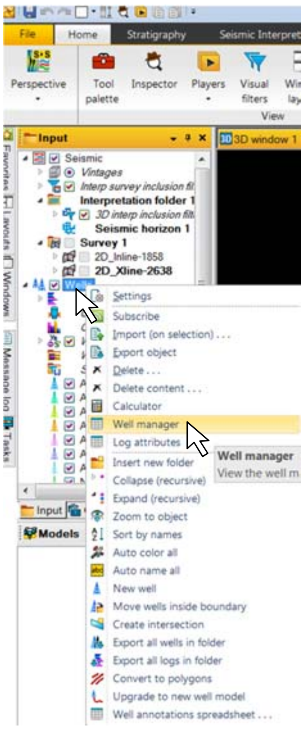


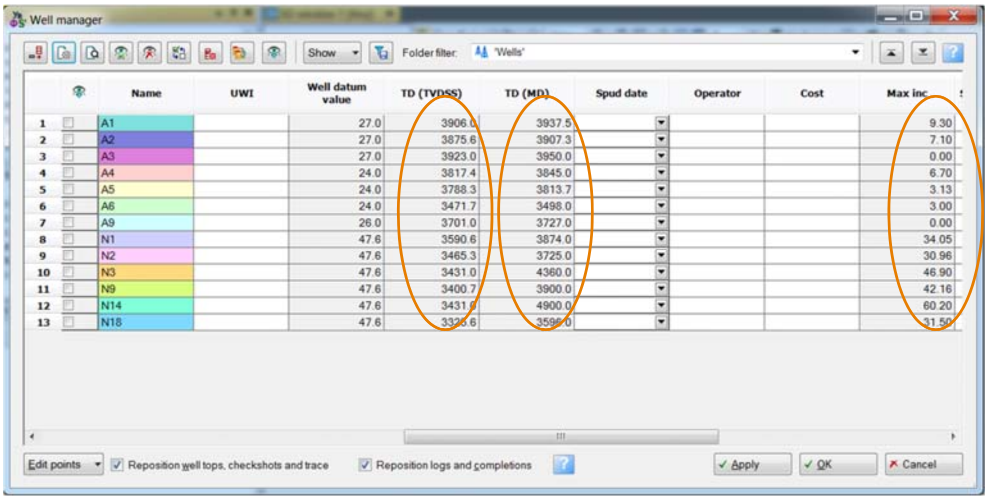






Well trajectories – Quality control





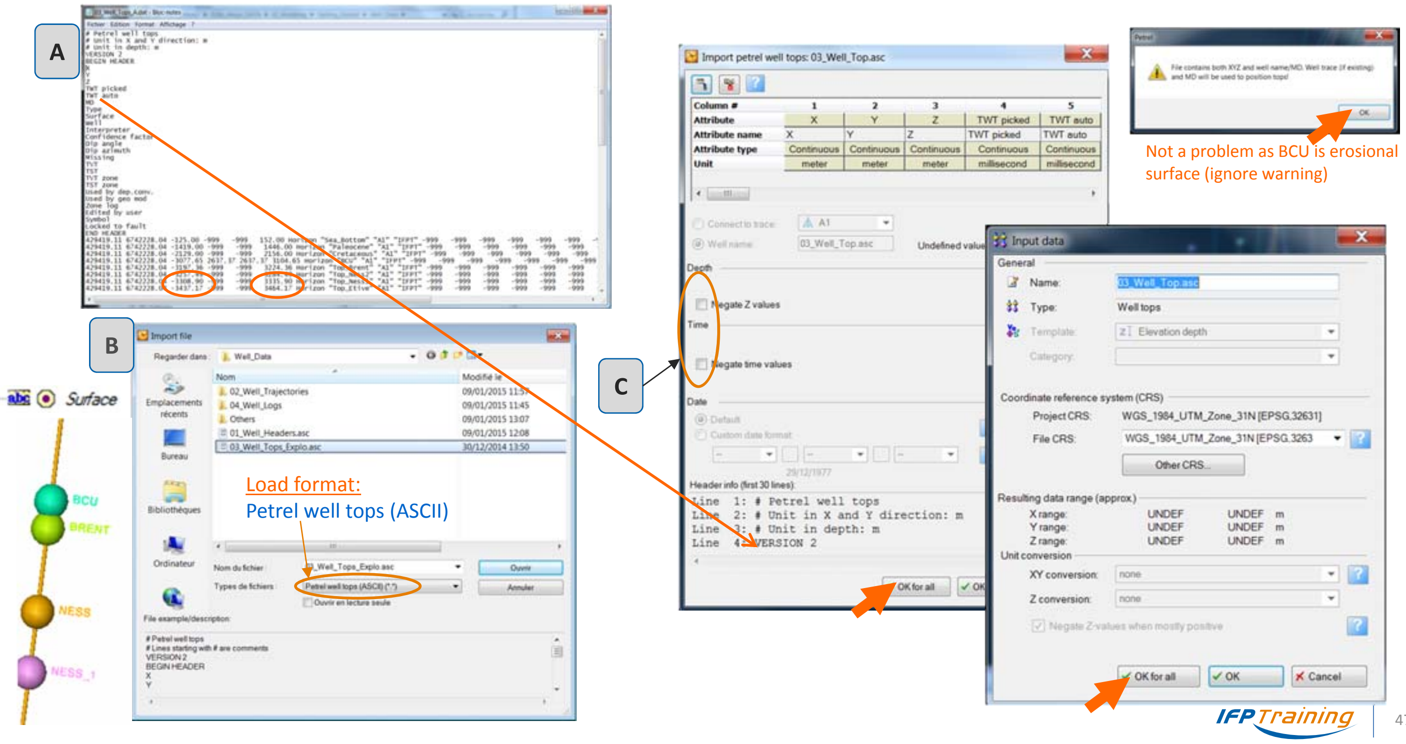
	Name	UWI	Well datum value	TD (TVDSS)	TD (MD)	Spud date	Operator	Cost	Max inc
1	A1		27.0	3906.0	3937.5				9.30
2	A2		27.0	3875.6	3907.3				7.10
3	A3		27.0	3923.0	3950.0				0.00
4	A4		24.0	3817.4	3845.0				6.70
5	A5		24.0	3788.3	3813.7				3.13
6	A6		24.0	3471.7	3498.0				3.00
7	A9		26.0	3701.0	3727.0				0.00
8	N1		47.6	3590.6	3874.0				34.05
9	N2		47.6	3465.3	3725.0				30.96
10	N3		47.6	3431.0	4360.0				46.90
11	N9		47.6	3400.7	3900.0				42.16
12	N14		47.6	3431.0	4900.0				60.20
13	N18		47.6	3326.6	3596.0				31.50

- Right click on the “well” icon in the “Input” window
- Open the “Well manager” to QC the import
- Check “TD (TVDSS)”, “TD (MD)” and “Max inc” columns

Well data from *ascii* file - *Well tops*

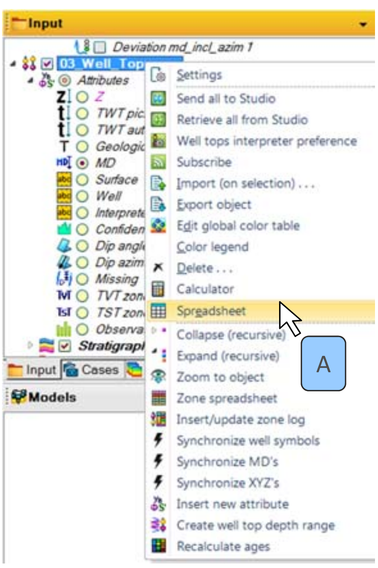
- **Well tops**
  - Edit *ascii* file to check the format - (A)
  - Import file using *Petrel well tops (ASCII)* - (B)
  - Unselect “Negate values” to convert Depth and Time values (C)

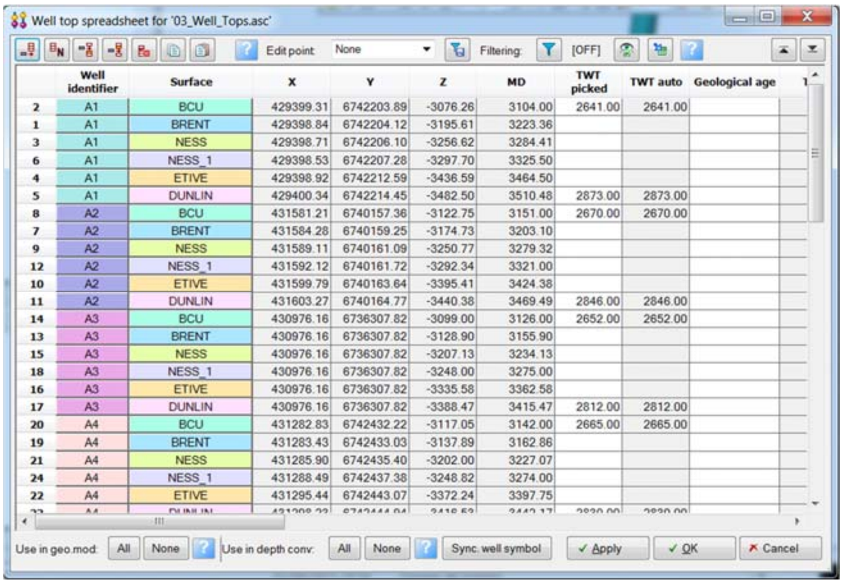
No need to “negate Z and Time values” as Z are already negative values, and Time already positives values



Well markers – Quality control

- **Well_Tops.asc QC**
  - Right click → Spreadsheet (A)
  - Check “TD (TVDSS)”, “TD (MD)” and “Max Inc.” columns

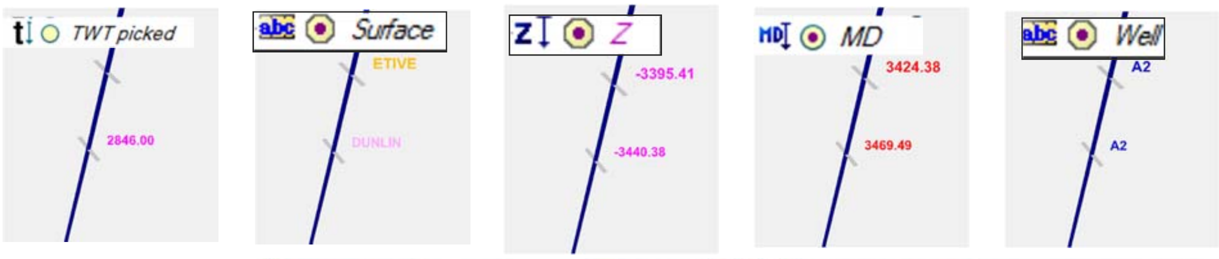


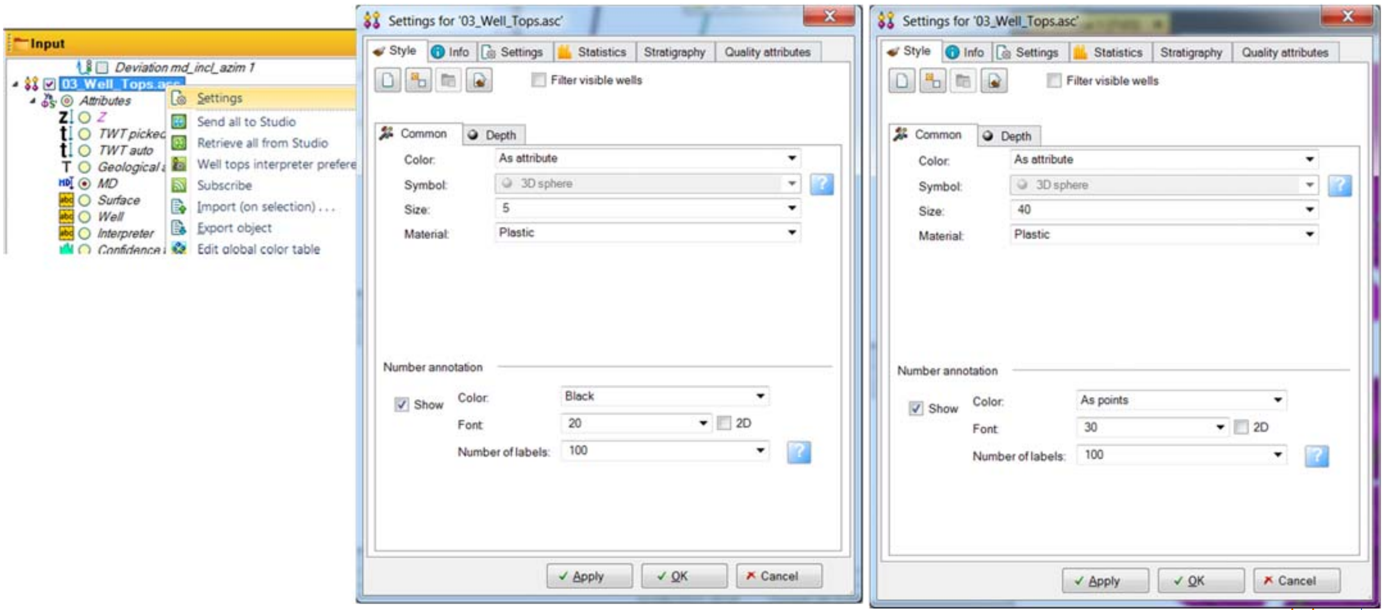

Well top spreadsheet for '03_Well_Tops.asc'

	Well identifier	Surface	X	Y	Z	MD	TWT picked	TWT auto	Geological age
2	A1	BCU	429399.31	6742203.89	-3076.26	3104.00	2641.00	2641.00	
1	A1	BRENT	429398.84	6742204.12	-3195.61	3223.36			
3	A1	NESS	429398.71	6742206.10	-3256.62	3284.41			
6	A1	NESS_1	429398.53	6742207.28	-3297.70	3325.50			
4	A1	ETIVE	429398.92	6742212.59	-3436.59	3464.50			
5	A1	DUNLIN	429400.34	6742214.45	-3482.50	3510.48	2873.00	2873.00	
8	A2	BCU	431581.21	6740157.36	-3122.75	3151.00	2670.00	2670.00	
7	A2	BRENT	431584.28	6740159.25	-3174.73	3203.10			
9	A2	NESS	431589.11	6740161.09	-3250.77	3279.32			
12	A2	NESS_1	431592.12	6740161.72	-3292.34	3321.00			
10	A2	ETIVE	431599.79	6740163.64	-3395.41	3424.38			
11	A2	DUNLIN	431603.27	6740164.77	-3440.38	3469.49	2846.00	2846.00	
14	A3	BCU	430976.16	6736307.82	-3099.00	3126.00	2652.00	2652.00	
13	A3	BRENT	430976.16	6736307.82	-3128.90	3155.90			
15	A3	NESS	430976.16	6736307.82	-3207.13	3234.13			
18	A3	NESS_1	430976.16	6736307.82	-3248.00	3275.00			
16	A3	ETIVE	430976.16	6736307.82	-3335.58	3362.58			
17	A3	DUNLIN	430976.16	6736307.82	-3388.47	3415.47	2812.00	2812.00	
20	A4	BCU	431282.83	6742432.22	-3117.05	3142.00	2665.00	2665.00	
19	A4	BRENT	431283.43	6742433.03	-3137.89	3162.86			
21	A4	NESS	431285.90	6742435.40	-3202.00	3227.07			
24	A4	NESS_1	431288.49	6742437.38	-3248.82	3274.00			
22	A4	ETIVE	431295.44	6742443.07	-3372.24	3397.75			

Use in geo.mod: All None | Use in depth conv: All None | Sync. well symbol | Apply | OK | Cancel

Well tops from *ascii* files - *Display well tops*

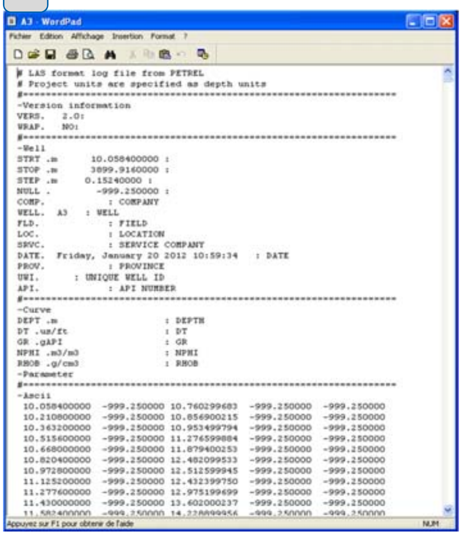




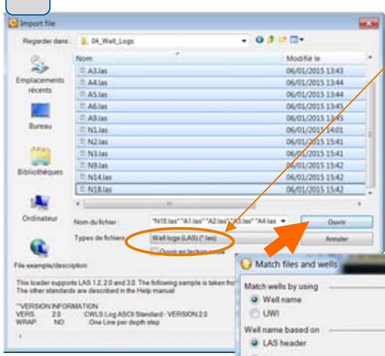
Well data from *ascii* file - *Well logs*

- **Well logs**
  - Edit *ascii* file to check the format (A)
  - Import file using *Well logs (*.las)* (B)

A

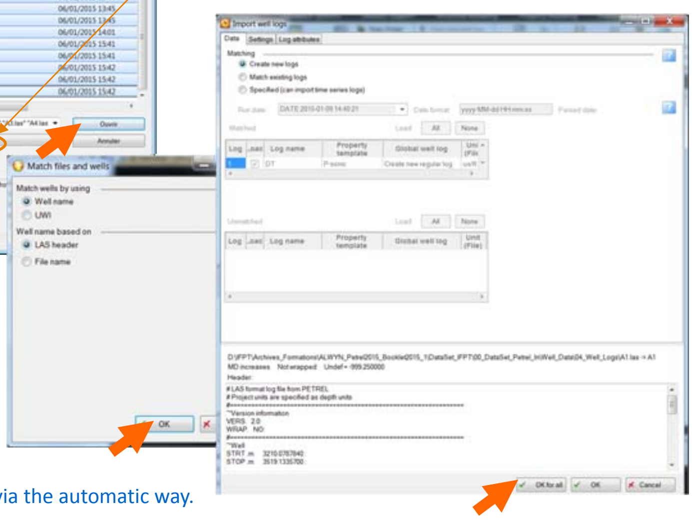


B



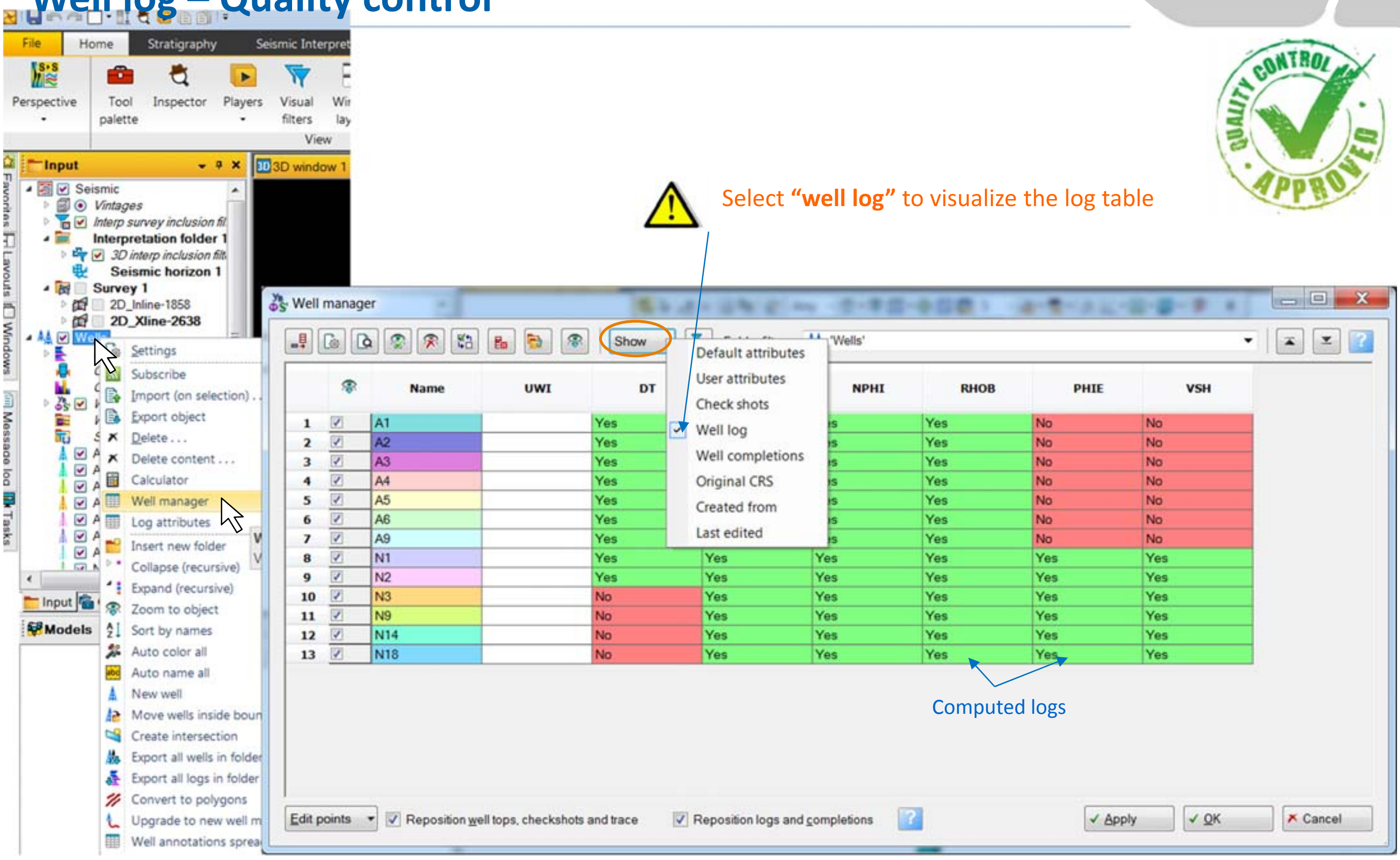
Load format:
Well logs (LAS) (*.las)

Sometimes, "Well logs (ASCII)" is a better format depending on Petrel version



If the matching between names, logs and templates is consistent, import via the automatic way.
If not, specify each trace, one by one.

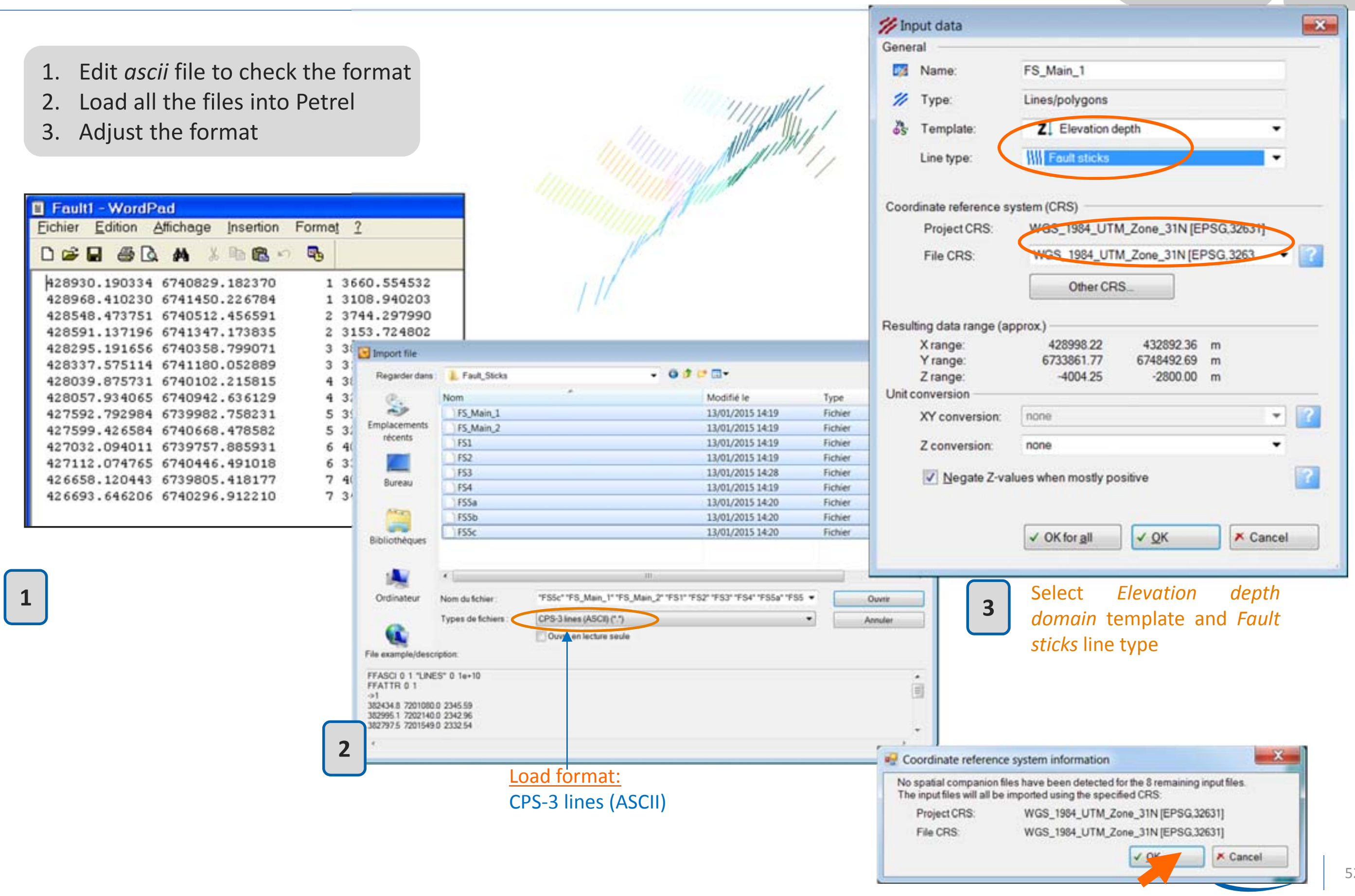
Well log – Quality control



- **Right click on the "well" icon in the "Input" window**
- **Open the "Well manager" to QC the import**

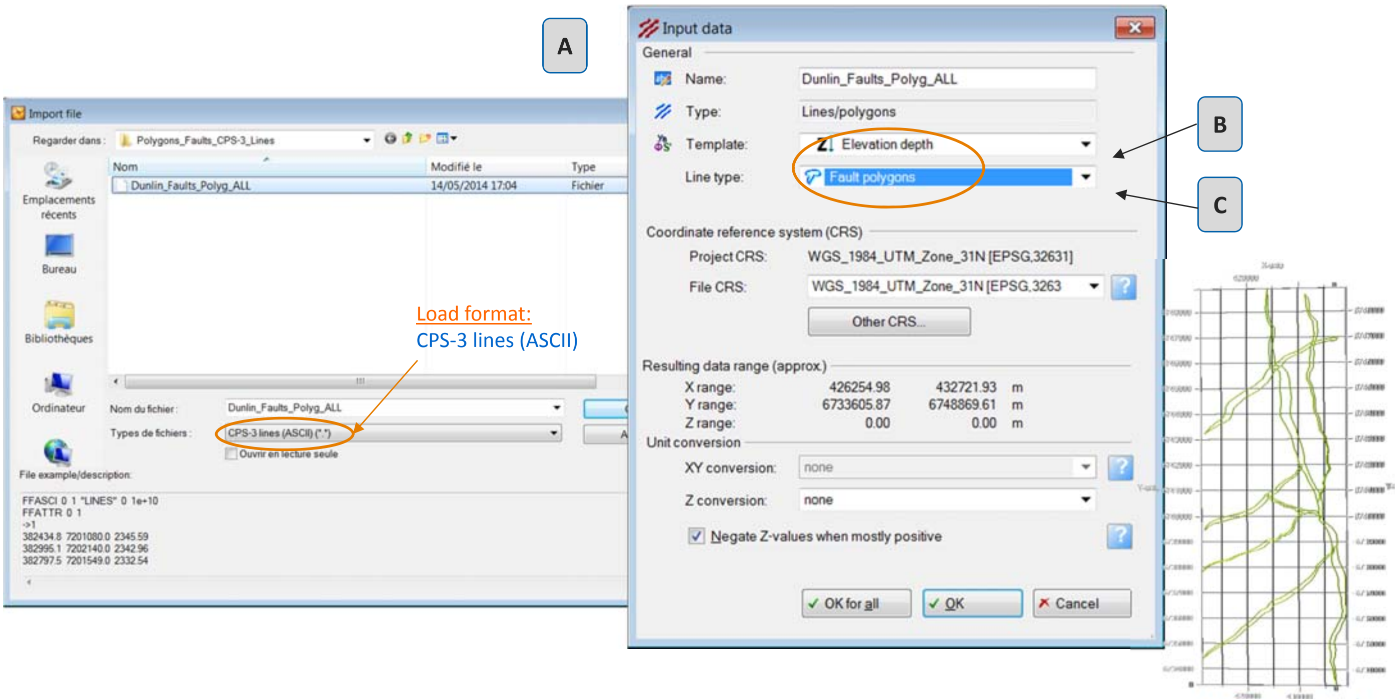
Fault sticks from *ascii* files

1. Edit *ascii* file to check the format
2. Load all the files into Petrel
3. Adjust the format



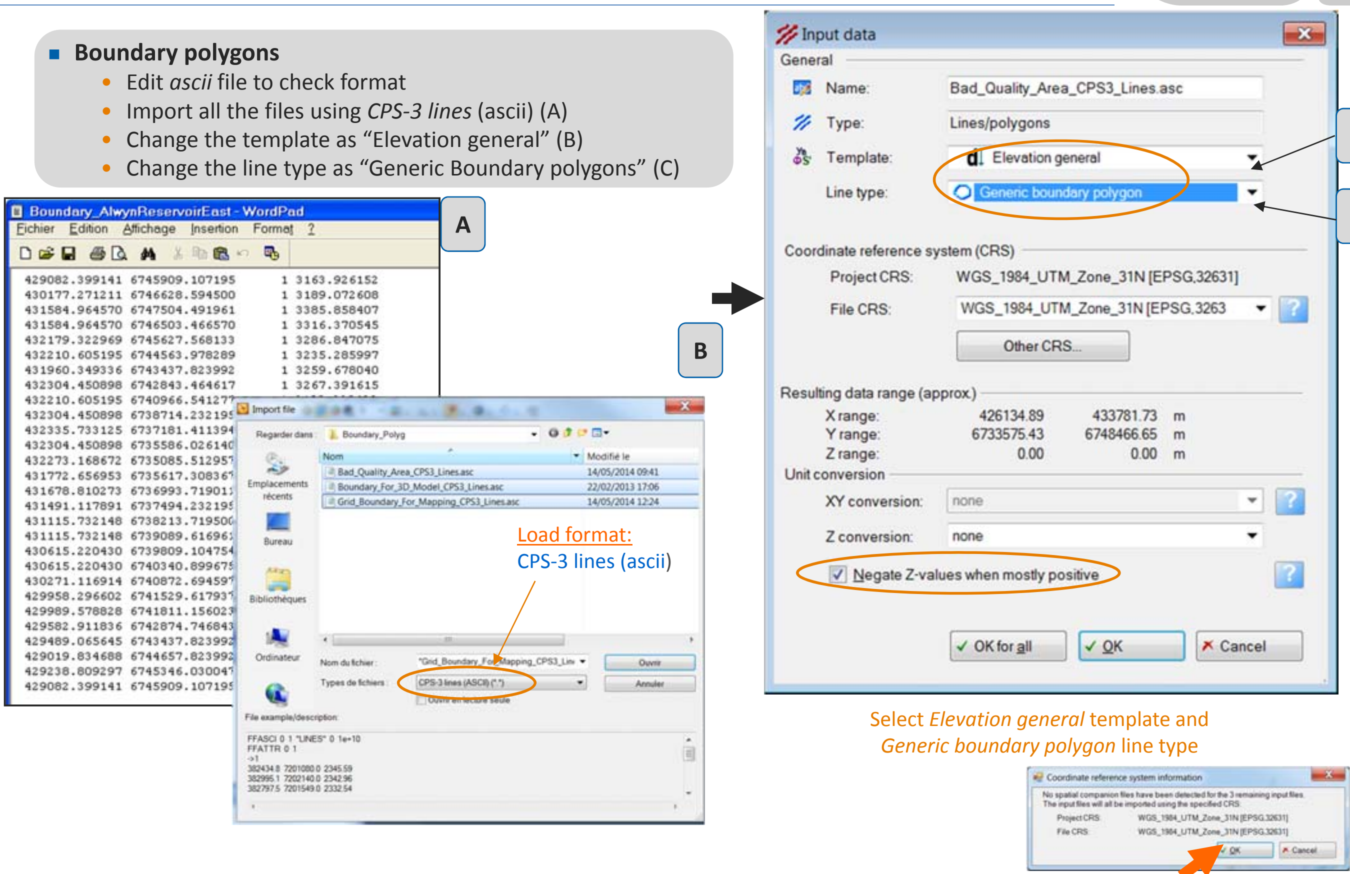
Fault polygons from *ascii* file (CPS-3)

- **Fault polygons**
  - Import "ALL" file using *CPS-3+ lines (ASCII)* (A)
  - Change the template as "Elevation depth" (B)
  - Change the line type as "Fault polygons" (C)



Boundary polygons from *ascii* file (CPS-3)

- **Boundary polygons**
  - Edit *ascii* file to check format
  - Import all the files using *CPS-3 lines* (ascii) (A)
  - Change the template as "Elevation general" (B)
  - Change the line type as "Generic Boundary polygons" (C)

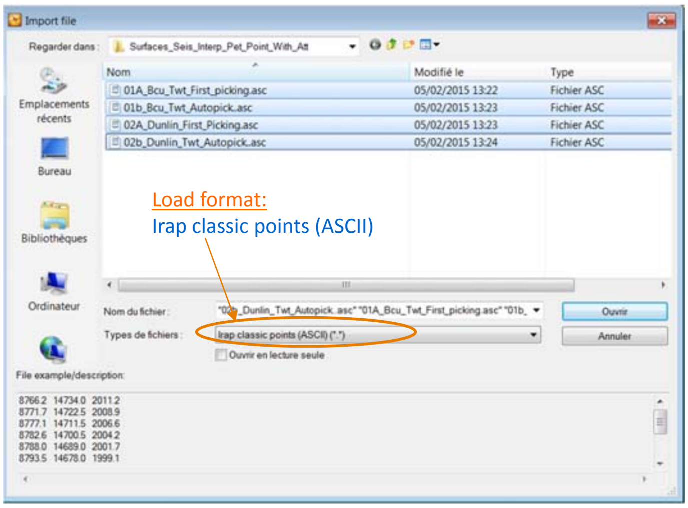


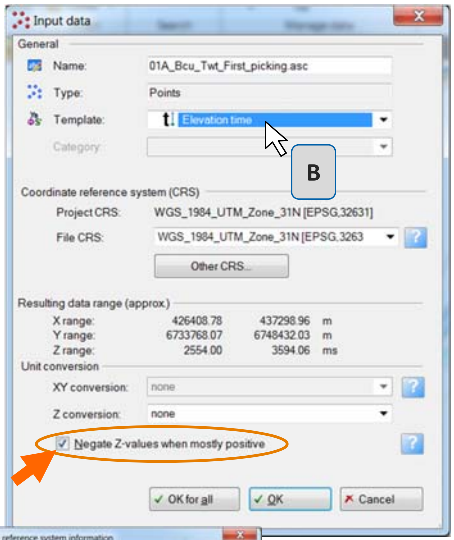
Select *Elevation general* template and *Generic boundary polygon* line type

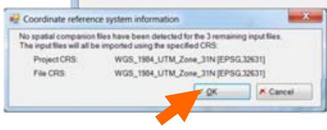
TWT grid points from *ascii* file

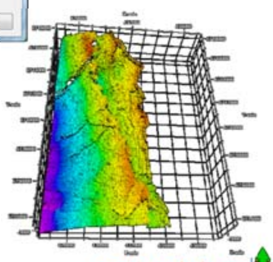
- **Import surfaces**
  - Import all the files using *Irap classic points (ASCII)* (A)
  - Change the template as “Elevation time” (B)
  - Negate Z-values (see warning)
  - Check data consistency

A







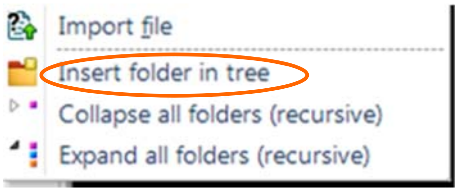


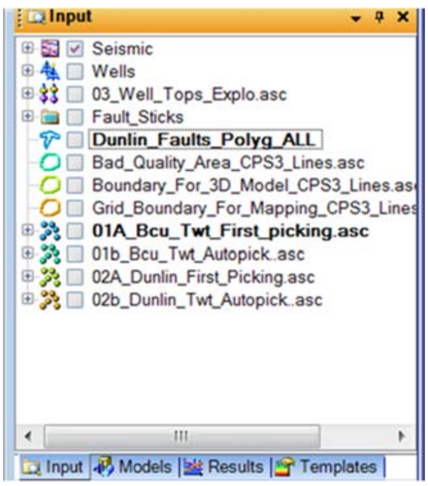
Warning

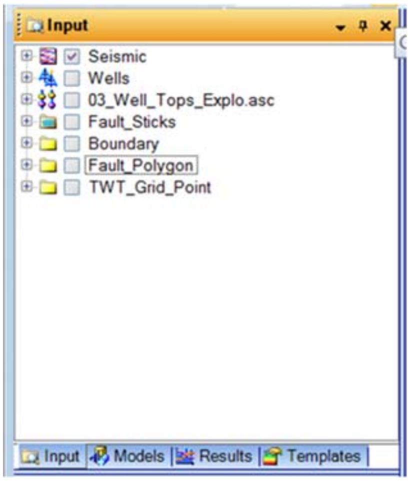
✓ Negate Z values since in Petrel sub-sea depth and time values must be negative !

Organize project

- **Manage data the same way as on “Windows Explorer”**
- **To insert a new folder in the tree**
  - Right click in the input window
  - Select “Insert folder in tree…”
  - Rename it (“Settings” double click)
  - Drag & drop data



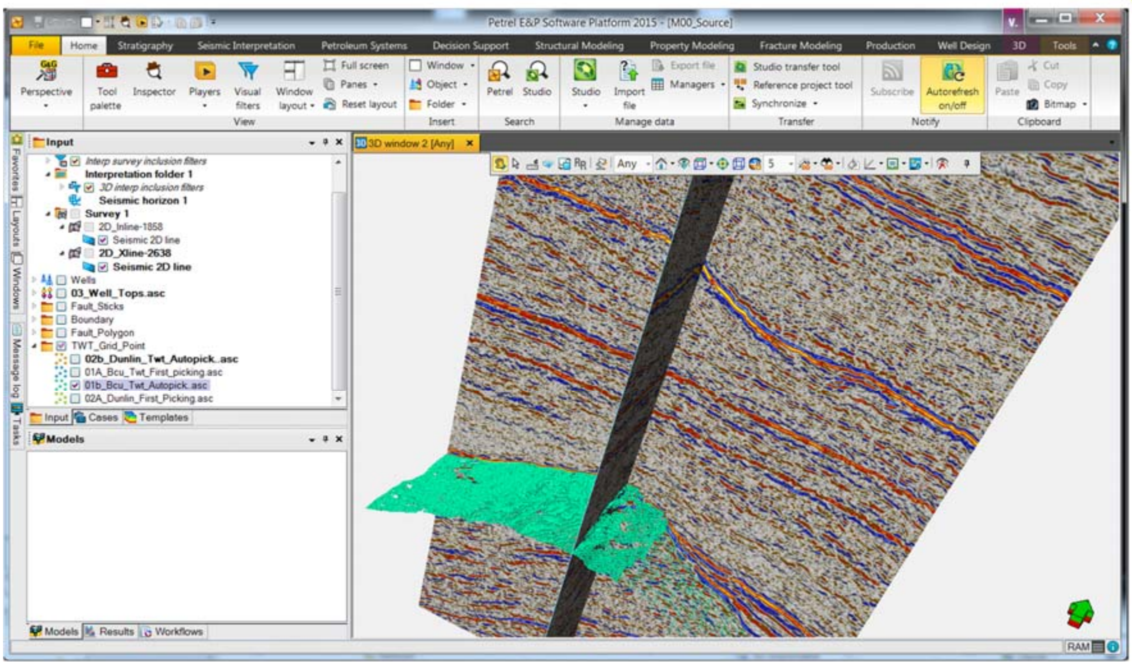




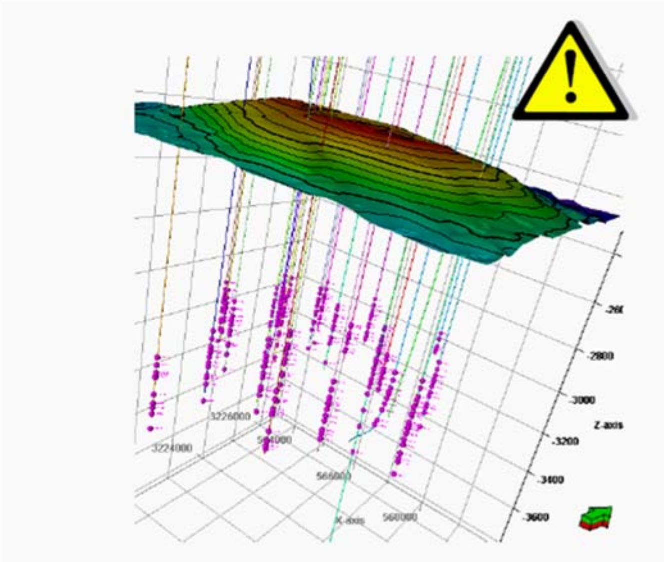
Quality control

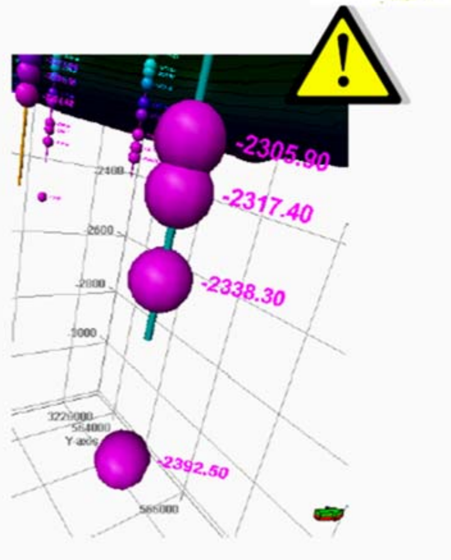
Quality Control - *Surfaces, faults, wells and seismic*

- **Check that seismic surfaces and well tops are consistently matched**
  - Display In-line, Cross-line and Horizon grids in the seismic block.
  - Control the matching between picking and interpolation.
  - Reporting analysis: Good/Bad matching between seismic and interpretation.



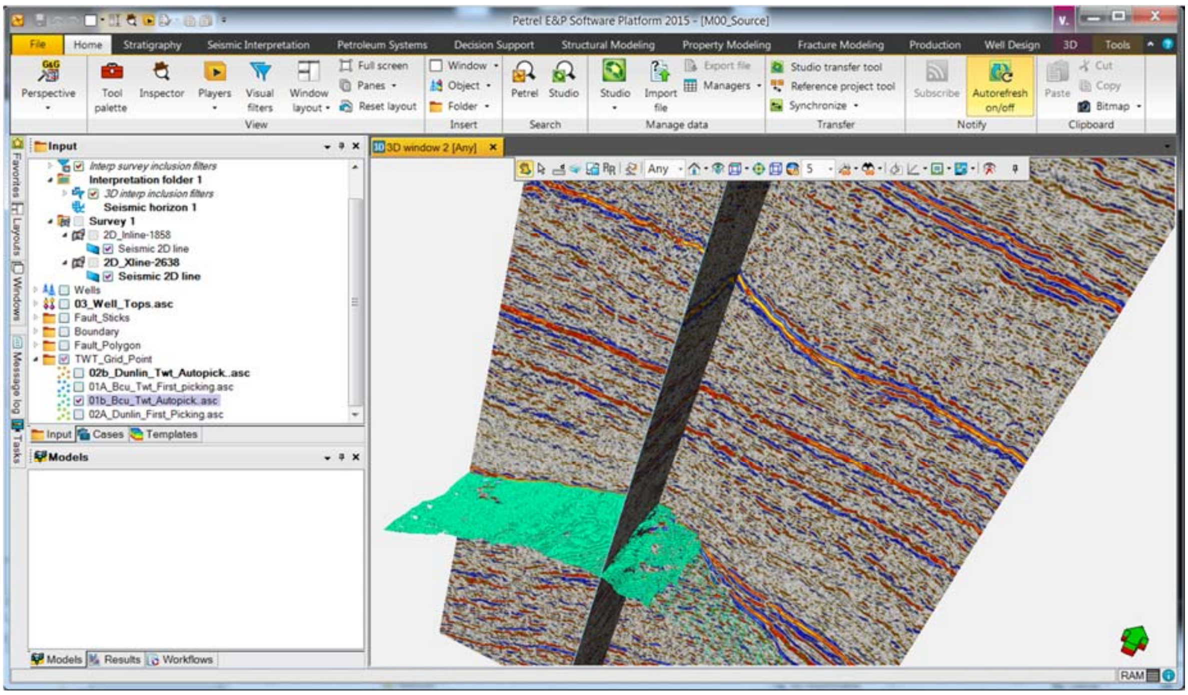
Input data & quality control





Due to the great variety of Petrel *import formats*, a thorough QC must be performed on imported *input data*.
Troubleshooting:
- If the surface is a few hundred meters above themarkers → *Problem of Kelly Bushing reference?*
- If a marker is below the end of well trajectory → *Mismatch between Z and TVD?*

M00_Source



Save project!

Alwyn static model architecture

Structural and stratigraphic characterization and modeling with Petrel©

Part 2C

Summary

- **Alwyn static model architecture**
  - Structural characterization
  - Structural modeling
  - Stratigraphic characterization
  - Stratigraphic modeling

Structural characterization with Petrel©

From Seismic (TWT) to Surface modeling (Depth)

M00_Source

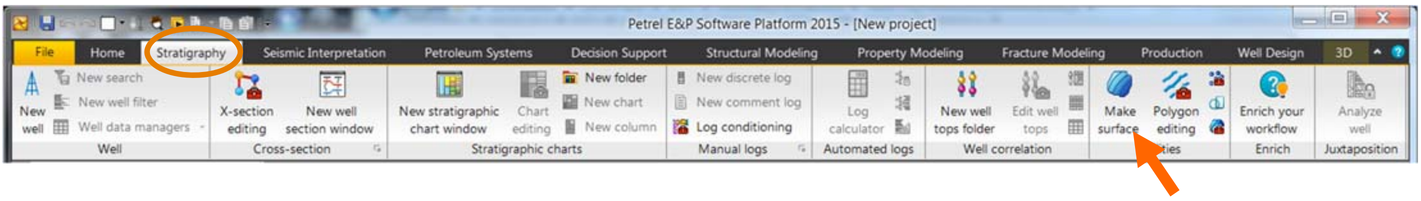
Summary

- Create surface with fault polygon
- Convert TWT to depth surface
- Create Brent by using Dunlin as reference

Create surface with fault polygon

Objectives - Summary

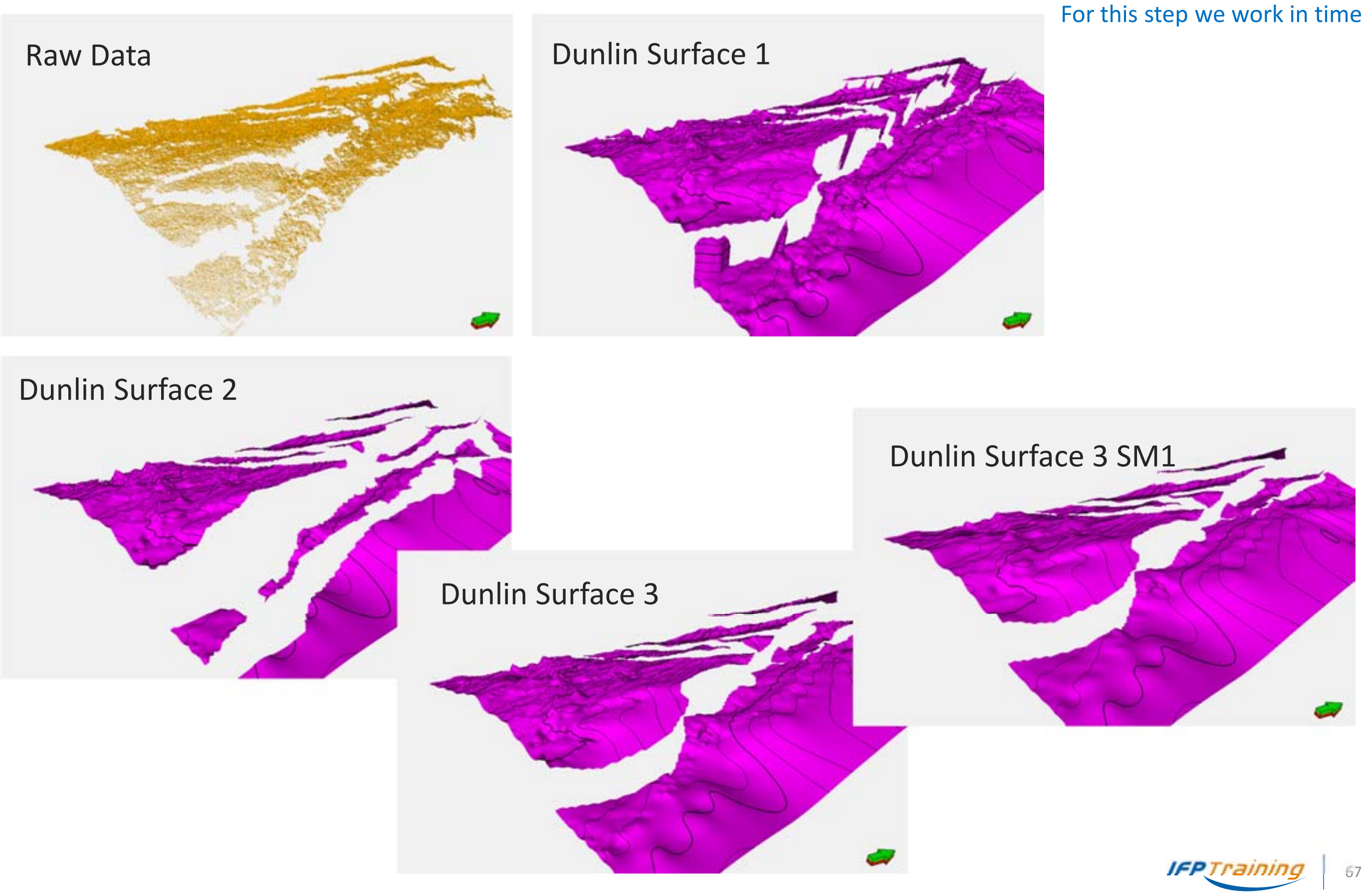
Stratigraphy ribbon



- **Make surface from the seismic data**
  - Settings for simple surface
  - Surface with fault polygon
  - Result
- **Eliminate the perturbed areas (clip points around faults & edges)**
  - Convert seismic to points
- **Create the final surface**
  - Display and color management – Smoothing
- **Organize the project**

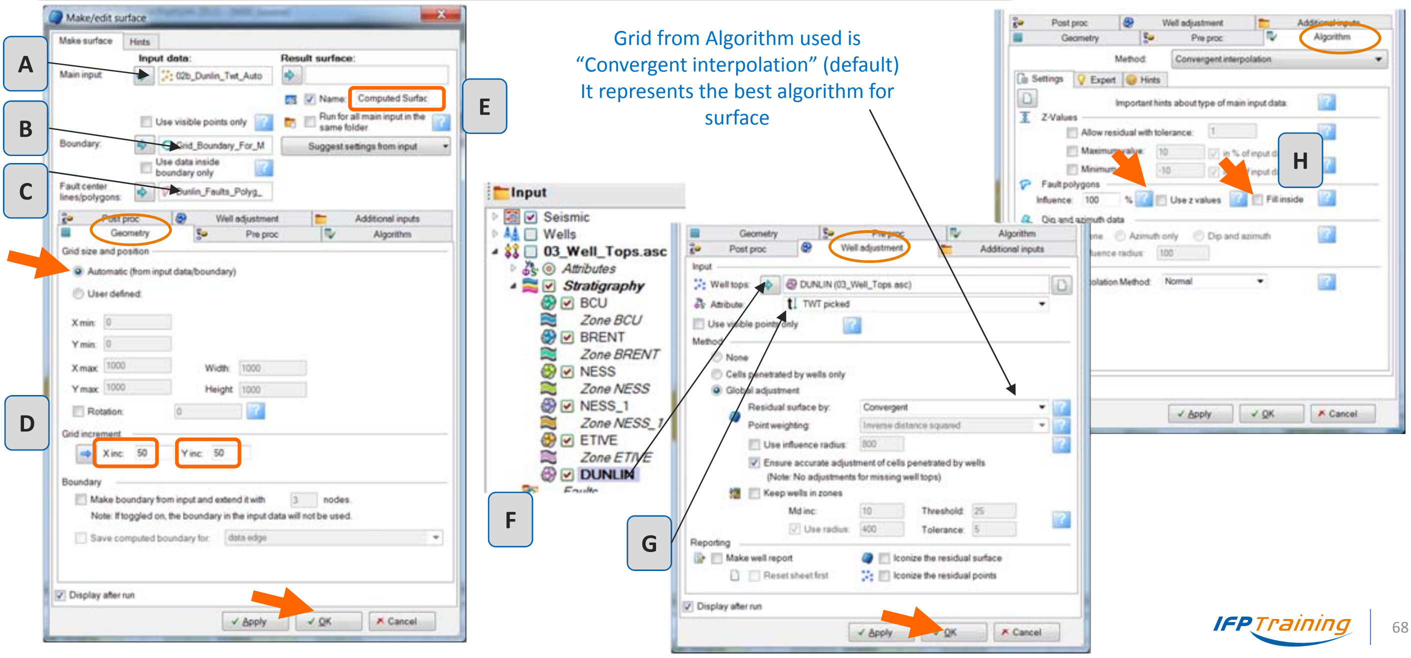
Steps for surface generation

For this step we work in time



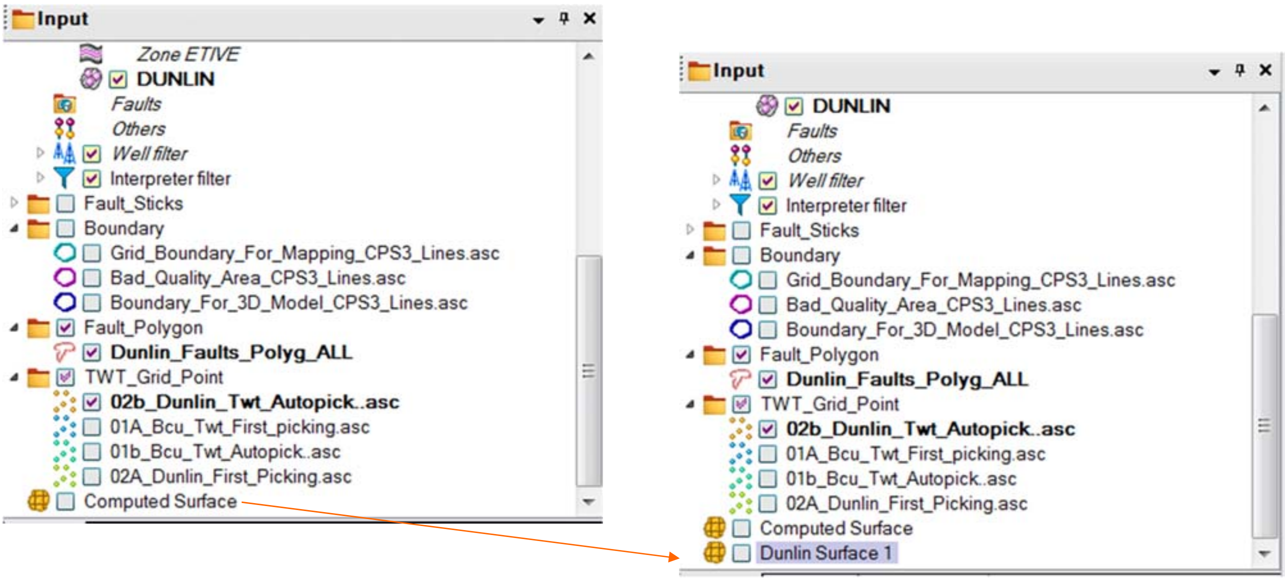
Build simple surface - *Make/Edit surface*

- **"Processes" panel → "Utilities" menu → select "Make/edit surface"**
  - On the Geometry window, select grid: "02b_Dunlin_Twt_Autopick.asc" as main input (A)
  - Select "Grid_Boundary_For_Mapping" as boundary (B)
  - Select "Dunlin_Faults_Polyg_ALL" as Fault Center lines/Polygons(C)
  - Tick "Automatic (from input data boundary)", Type in 50 as grid increment (D)
  - Name it "Computed Surface" (E)
  - On the Well adjustment window, select Dunlin Well top from (F) and select TWT Picked (G)
  - On the Algorithm window, Unselect Use Z value and Fill inside (H) and OK



Build simple surface - *Make/Edit surface*

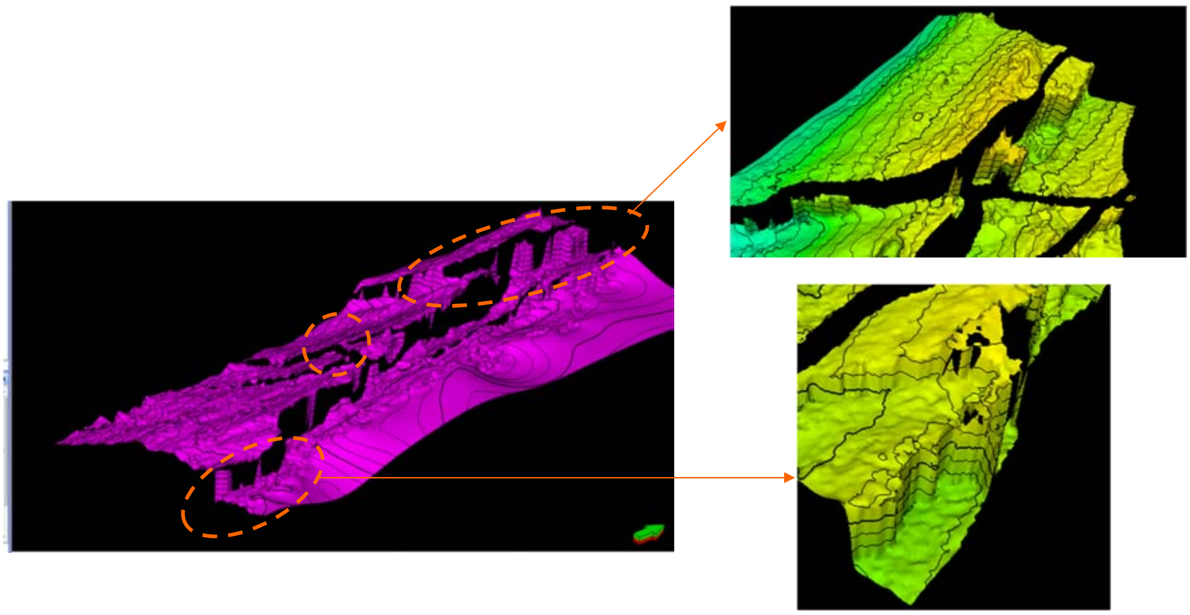
- **"Make/edit surface" in Processes/Utilities panel**
  - Copy the Computed Surface as Dunlin Surface 1



⚠ Warning: The *Computed Surface* buffer file is updated after each iteration: previous result is overwriten!

Check data consistency

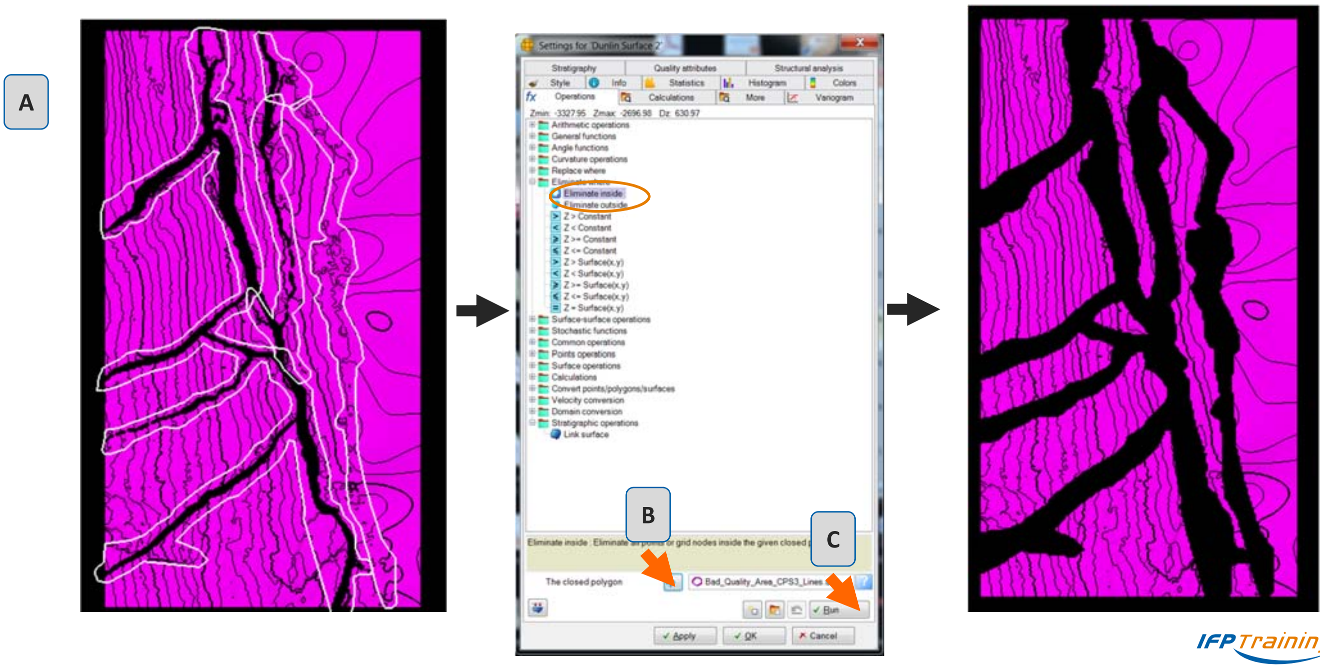
- **Look around the faults and edges for perturbations (lack of data, seismic interferences, calculation artifacts, bad values…)**



If perturbations seem too important, you may ask the geophysicist to double check the picking in problematic/dubious areas.

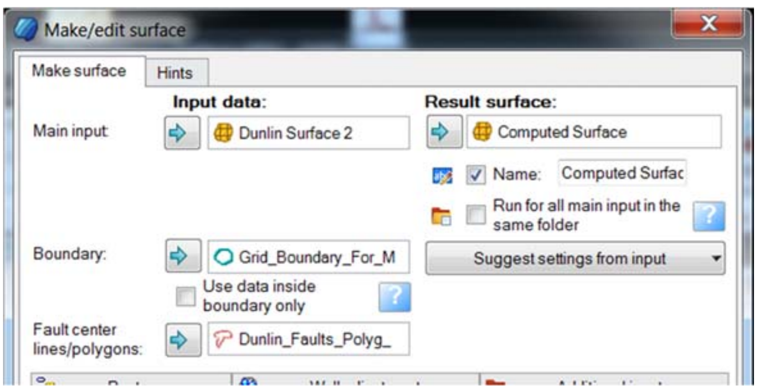
Eliminate points in perturbed areas

- **Clean up surface**
  - Copy the previous file Dunlin Surface 1 as Dunlin Surface 2
  - Settings --> Operations
  - Eliminate Where → Eliminate inside → Select the polygon “Bad_Quality_Area_CPS3_Lines.asc” (B) and press “Run”



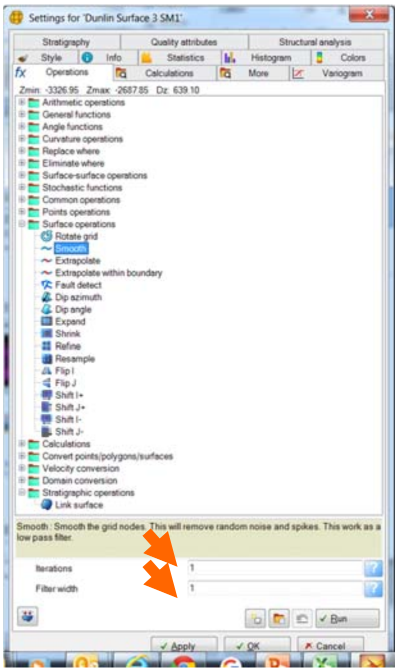
Create final surface

- **Extrapolate and extend the cleaned surface to fault polygon edge**
  - Make surface
  - Change Main input as “Dunlin Surface 2” and use the same parameter as the one used to create Surface Dunlin 1
  - *Copy, Paste and Rename final file* as Dunlin Surface 3



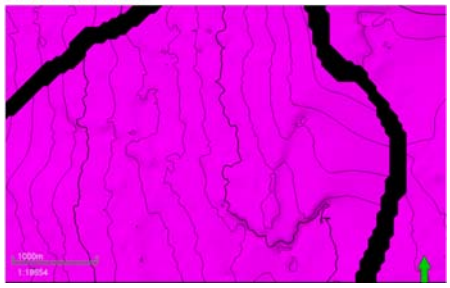
Create final surface

- **Smoothing**
  - *Copy, Paste and Rename* Dunlin Surface 3 as Dunlin Surface 3 SM1
  - In Settings → *“Operations* → *Surface operations* → *Smooth*”. Type in 1 for *smoothing level* (1 = only one iteration). Smooth surface until it gets simple and nice!

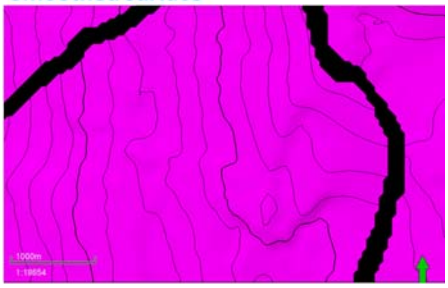


1 iteration is enough !

Raw surface



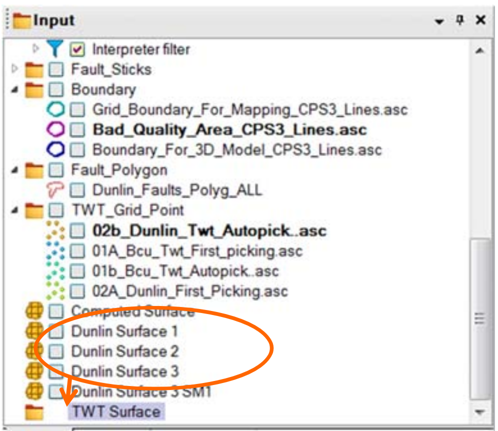
Smoothed surface

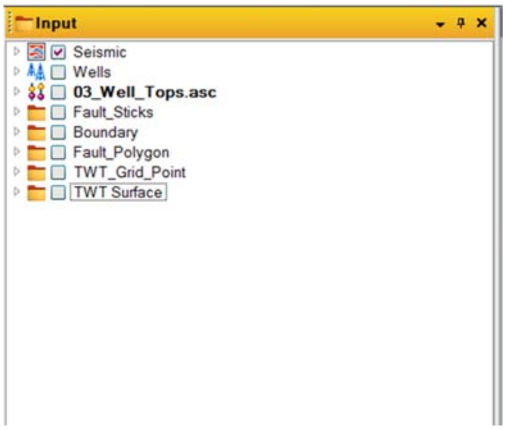


Organize your project

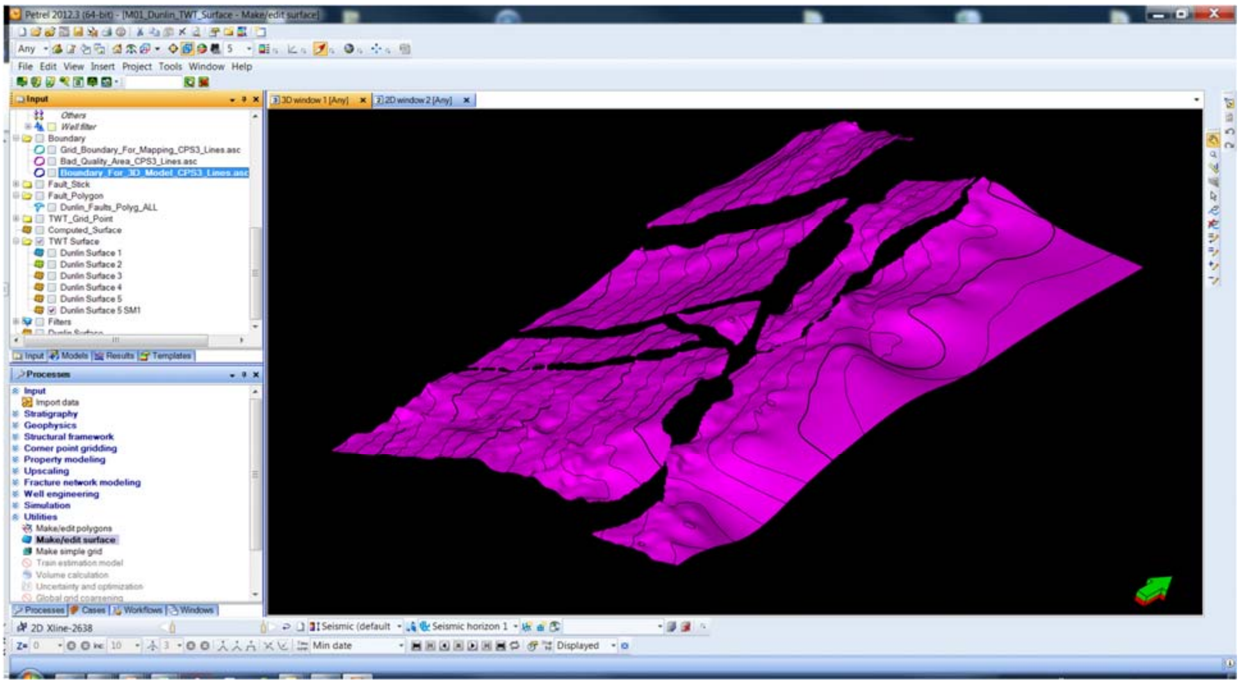
- **All Dunlin surfaces using TWT data are now created**

  Before continuing further, organize your input window:
  - Input folders in tree:
    - One folder with all polygons (should be already done…)
    - One folder with all surfaces TWT
  - Your project ***Input window*** should look like the one below:





M01_Dunlin_TWT_Surface



Save project !

Convert TWT to depth surface

Simplified procedure

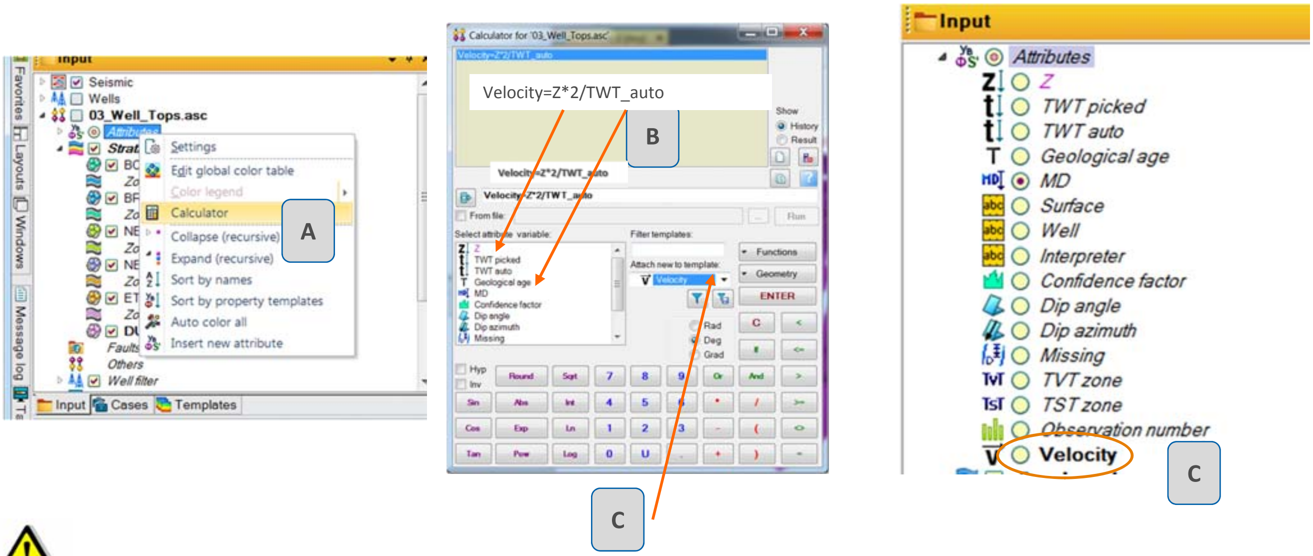
M01_Dunlin_TWT_Surface

Summary

- **Velocity map from well tops**
  - Create a velocity attribute on well tops
  - Create a velocity map
- **Convert TWT surface to depth surface**
  - Calculator
  - Match surface on well tops

Velocity map (1/3)

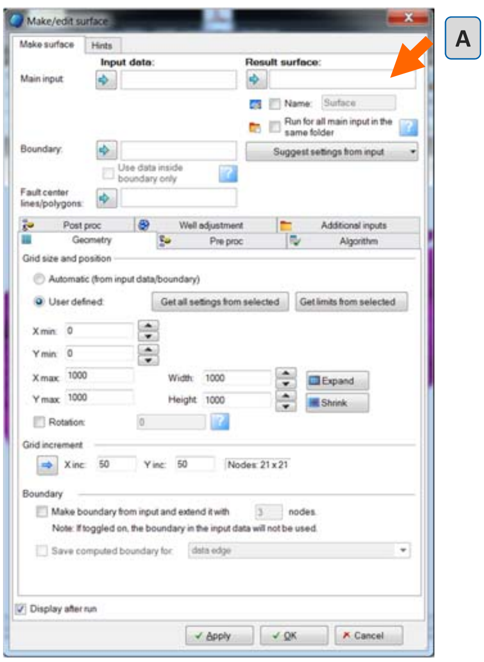
- **Create velocity attribute on well tops**
  - In *Well_Top.dat* right click on *Attribute* and select *Calculator* (A)
  - In the expression banner, enter **"Velocity = Z*2/TWT_auto"** (B) (Select formula elements directly in input list)
  - Select the template "Velocity" (C)
  - Click on *ENTER*: the new *"Velocity"* attribute is generated (C)

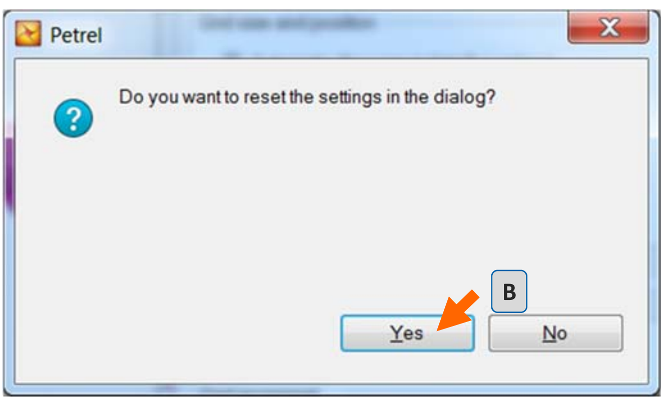


Always leave "Well filter" *ticked on.*

Velocity map (2/3)

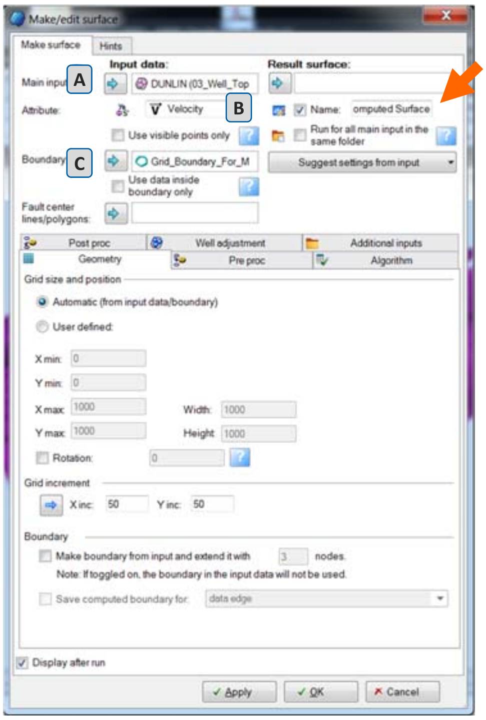
- **Create velocity map from velocity attributes**
  - *Make surface*
  - Clean Panel: Click on Result Surface (A) and delete
  - Yes (B)

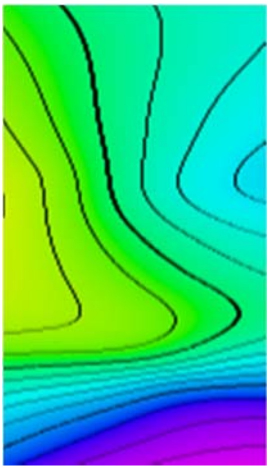




Velocity map (2/2)

- **Create the velocity map from velocity attributes**
  - Select *Well Top (03_Well_Top.asc)* → *Stratigraphy* → ***Top_Dunlin*** as ***Main input*** (A)
  - Select *Velocity* as *Attribute* (B)
  - Select ***Grid_Boundary_For_Mapping*** (C)
  - *Name* it "*Computed Surface*" (D)
  - In *Settings* → *Info,* replace icon with following:
  - Copy/Paste "Computed Surface" as "Dunlin Velocity"
  - Display the map in a 2D window or in a Map window
  - Adjust the color table on the selected map

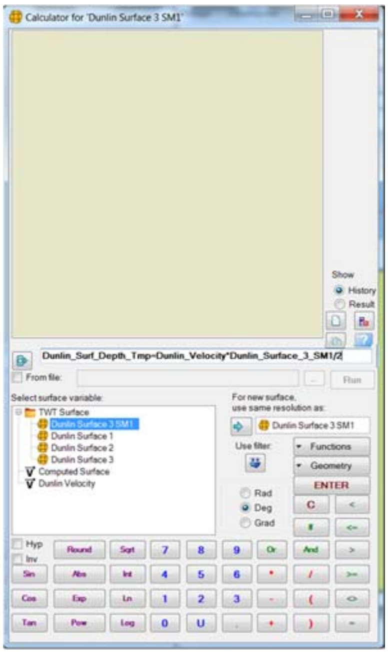




Velocity map
(screen shot)

Convert TWT surface to depth surface using velocity map

- **Calculate the depth surface**
  - Right click on "Dunlin Surface 3 SM1" and select *Calculator*
  - In the expression banner type in:
    "Dunlin_Surf_Depth_Tmp=Dunlin_Velocity_map*Dunlin_Surface_3_SM1/2"



Velocity = Depth / Time
↓
Depth map = Velocity map × TWT map/2

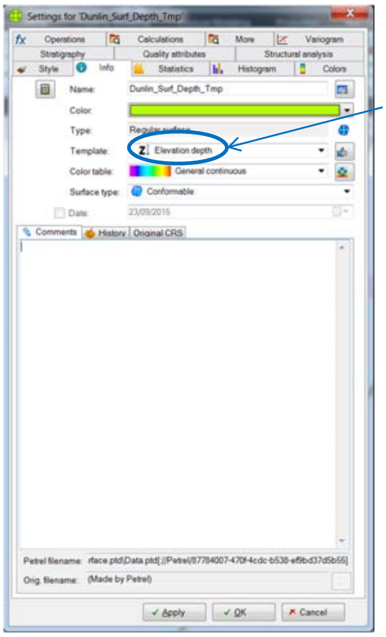
Convert TWT surface to depth surface using velocity map

- **Calculate the depth surface**
  - Select “Dunlin_Surface_Depth_Tmp” → Settings
  - Modify the template as “Z elevation depth”

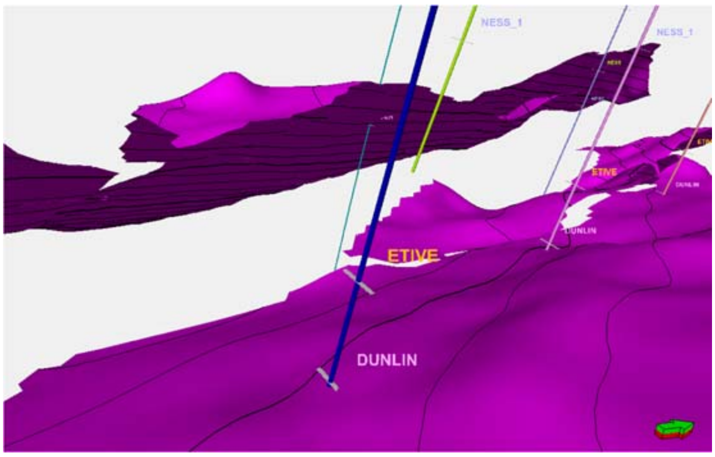
Velocity = Depth / Time

↓

Depth map = Velocity map × TWT map/2

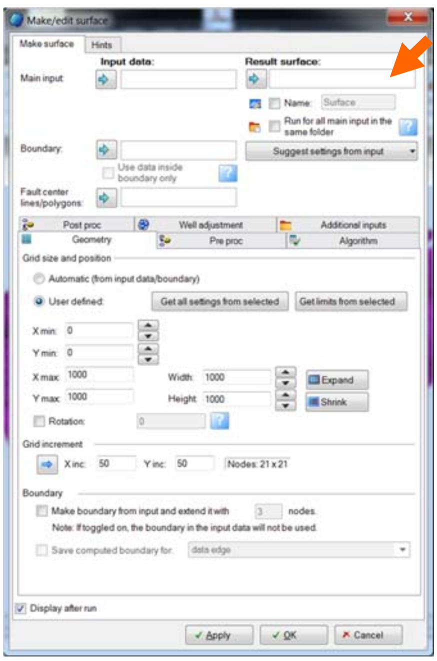


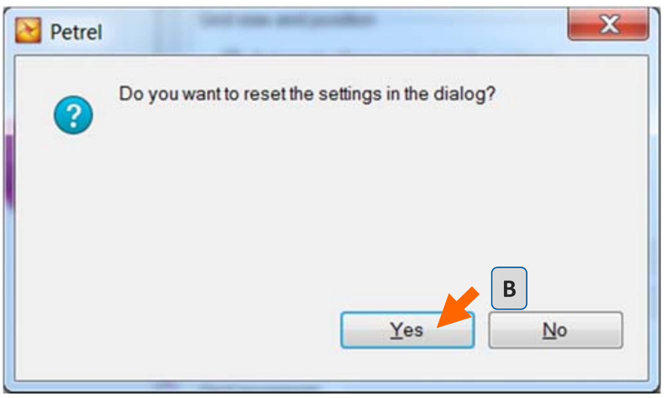
Data in depth
→ switch “Template” reference to “Z”



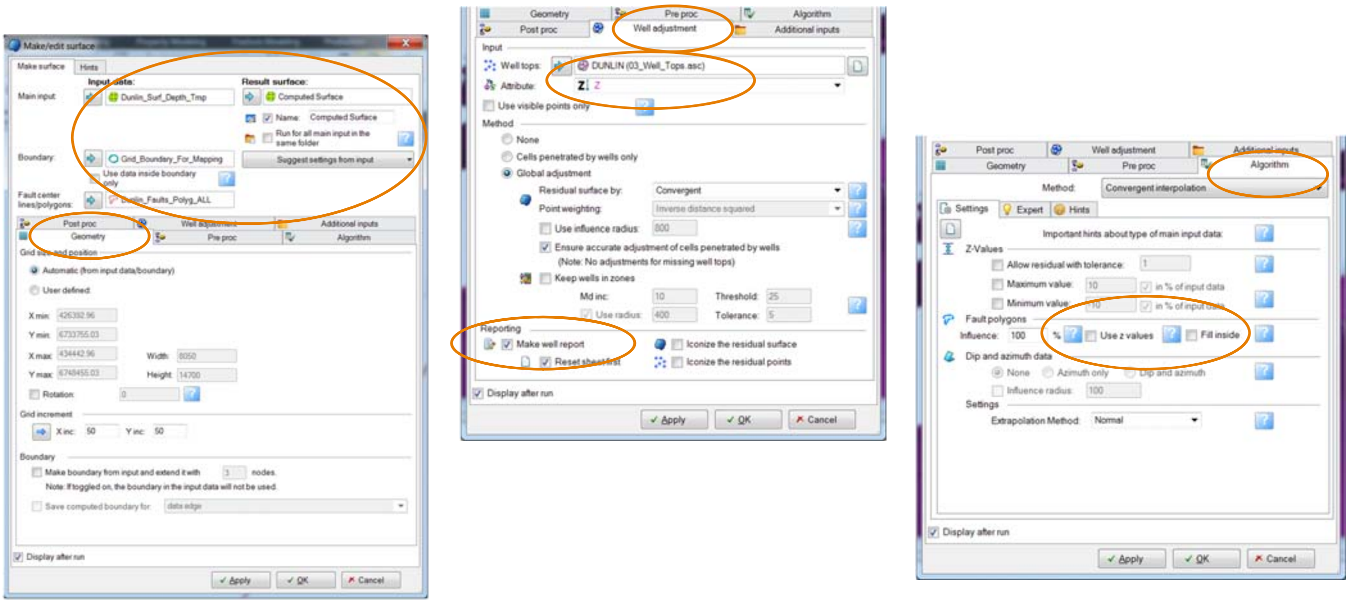
Dunlin Depth surface well adjustment 1/3

- **Create the velocity map from velocity attributes**
  - *Make surface*
  - Clean Panel: Click on Result Surface (A) and delete
  - Yes (B)

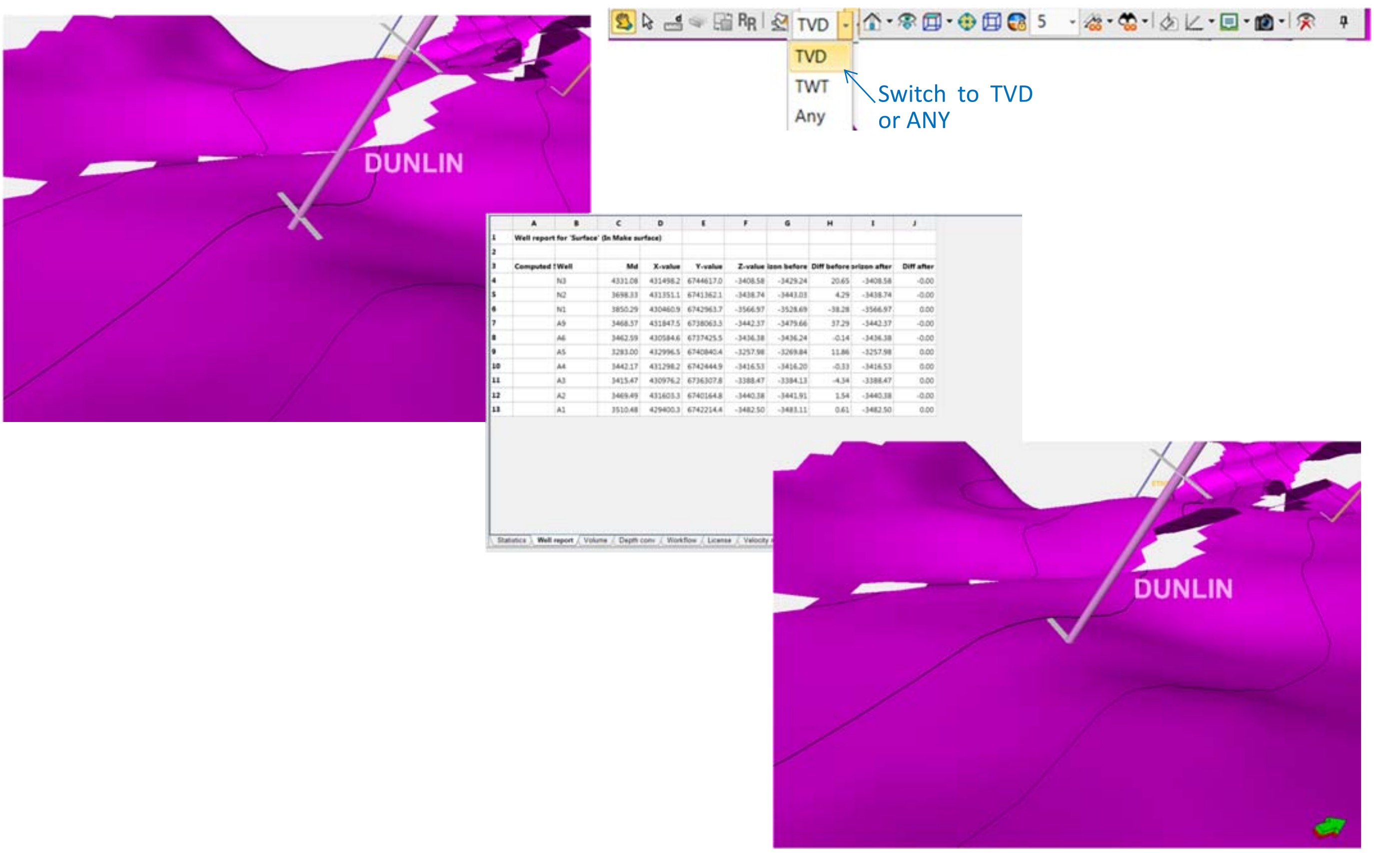




Dunlin Depth surface well adjustment 2/3

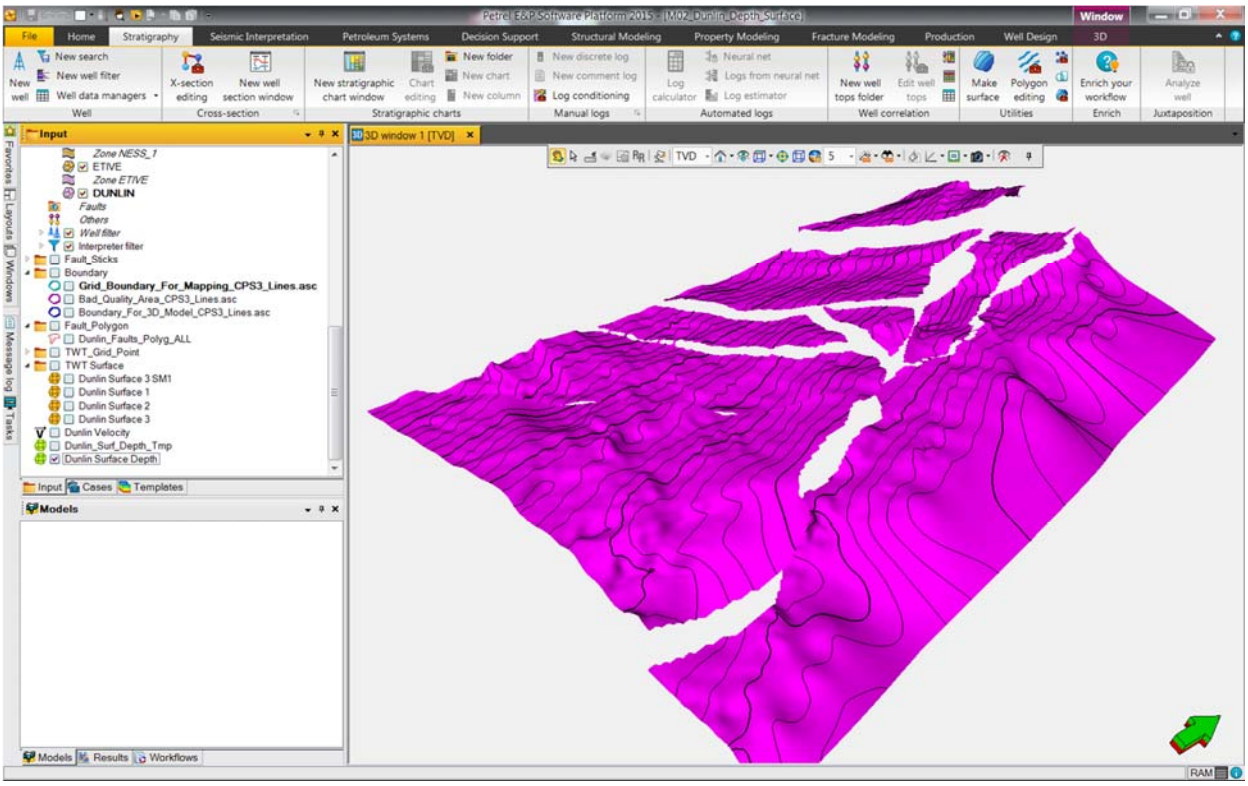


Dunlin Depth surface well adjustment 3/3



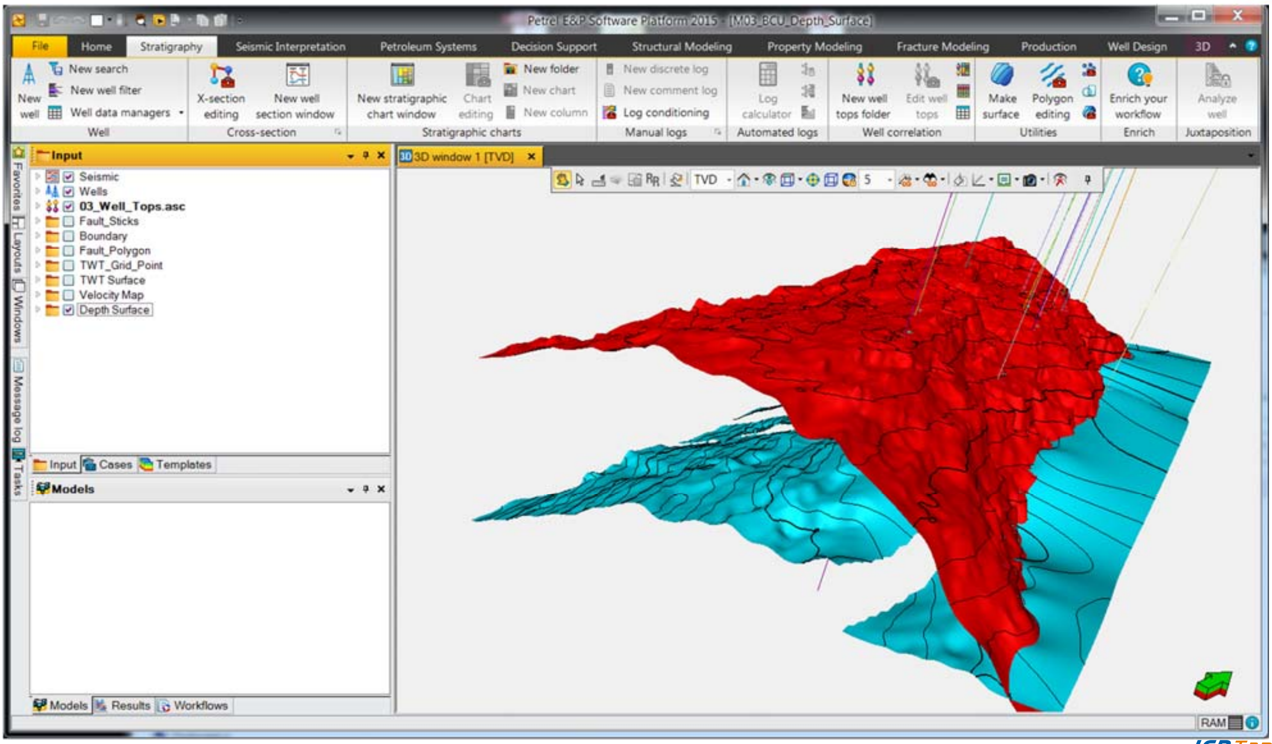
	A	B	C	D	E	F	G	H	I	J
1	Well report for 'Surface' (In Make surface)									
2										
3	Computed !	Well	Md	X-value	Y-value	Z-value	izon before	Diff before	orizon after	Diff after
4		N3	4331.08	431498.2	6744617.0	-3408.58	-3429.24	20.65	-3408.58	-0.00
5		N2	3698.33	431351.1	6741362.1	-3438.74	-3443.03	4.29	-3438.74	-0.00
6		N1	3850.29	430460.9	6742963.7	-3566.97	-3528.69	-38.28	-3566.97	0.00
7		A9	3468.37	431847.5	6738063.3	-3442.37	-3479.66	37.29	-3442.37	-0.00
8		A6	3462.59	430584.6	6737425.5	-3436.38	-3436.24	-0.14	-3436.38	-0.00
9		A5	3283.00	432996.5	6740840.4	-3257.98	-3269.84	11.86	-3257.98	0.00
10		A4	3442.17	431298.2	6742444.9	-3416.53	-3416.20	-0.33	-3416.53	0.00
11		A3	3415.47	430976.2	6736307.8	-3388.47	-3384.13	-4.34	-3388.47	0.00
12		A2	3469.49	431603.3	6740164.8	-3440.38	-3441.91	1.54	-3440.38	-0.00
13		A1	3510.48	429400.3	6742214.4	-3482.50	-3483.11	0.61	-3482.50	0.00

M02_Dunlin_Depth_Surface



M03_BCU_Depth_Surface

- **Applications Hands-on**
  - Create BCU_TWT_Surface (Same as for Dunlin but without any fault)
  - Apply the same procedure to BCU surface using “BCU Velocity map”



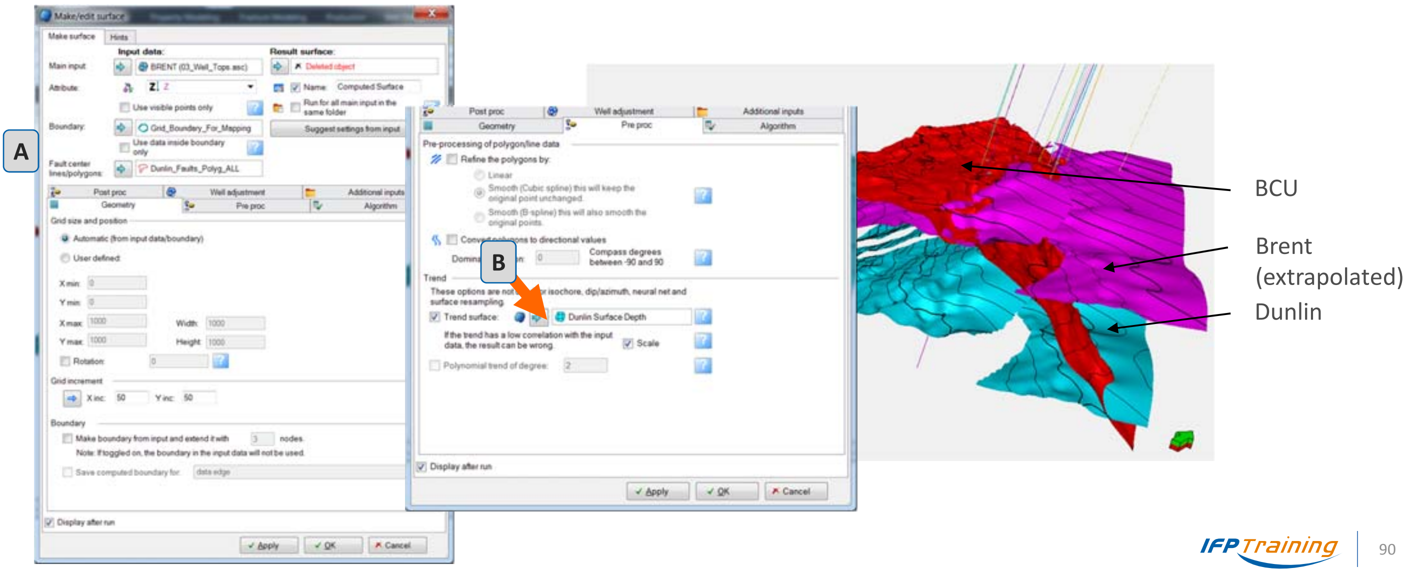
Create Brent by using Dunlin as reference

M03_BCU_Depth_Surface

Use Dunlin top to build Brent top

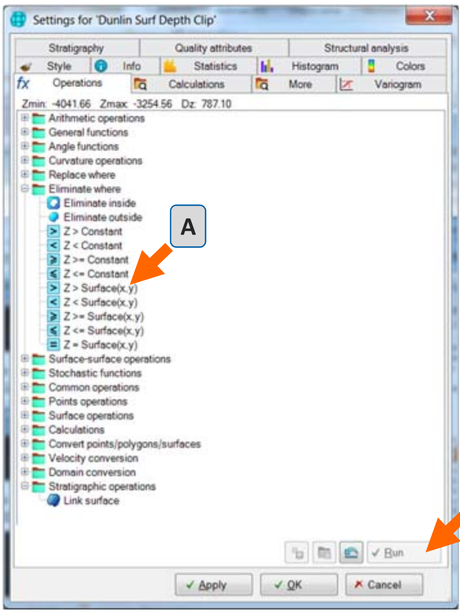
- **The reservoir top (Brent) is not interpreted (because not well visible) on seismic but it can be created by using the reservoir base (Dunlin) and via shifting operations**
- **A surface (Brent) is created from a trend (Dunlin)**
  - Select *Make surface* (in *ribbon*)
  - Select *Top_Brent (Well_Tops.dat)* as *Main input*
  - Select *Z* as *Attribute*
  - Select *Grid boundary_For_Mapping.asc* in *Boundary and Dunlin_Fault_Polyg_All**
  - Tick *Automatic* in *Geometry* tab (A)
  - In *Pre-proc* tab, indicate *Dunlin* as *Trend surface* (B)

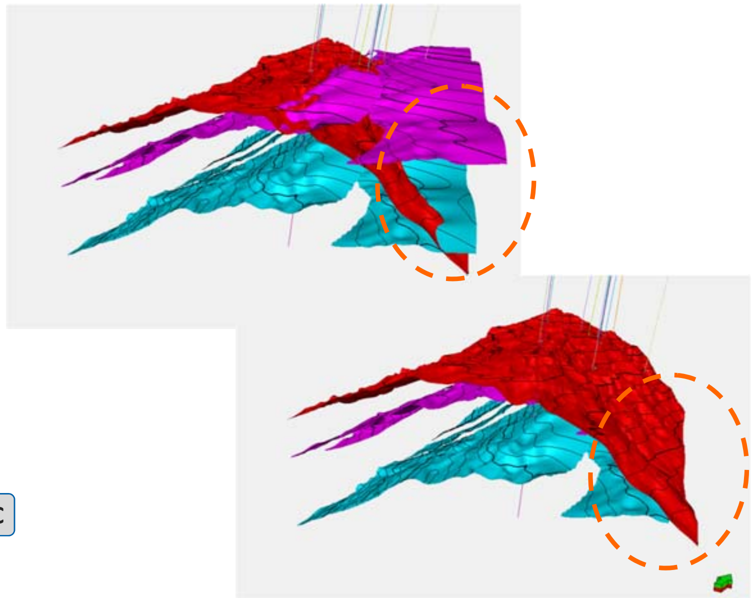
To simplify data manipulation use the same fault network both for Dunlin and Brent



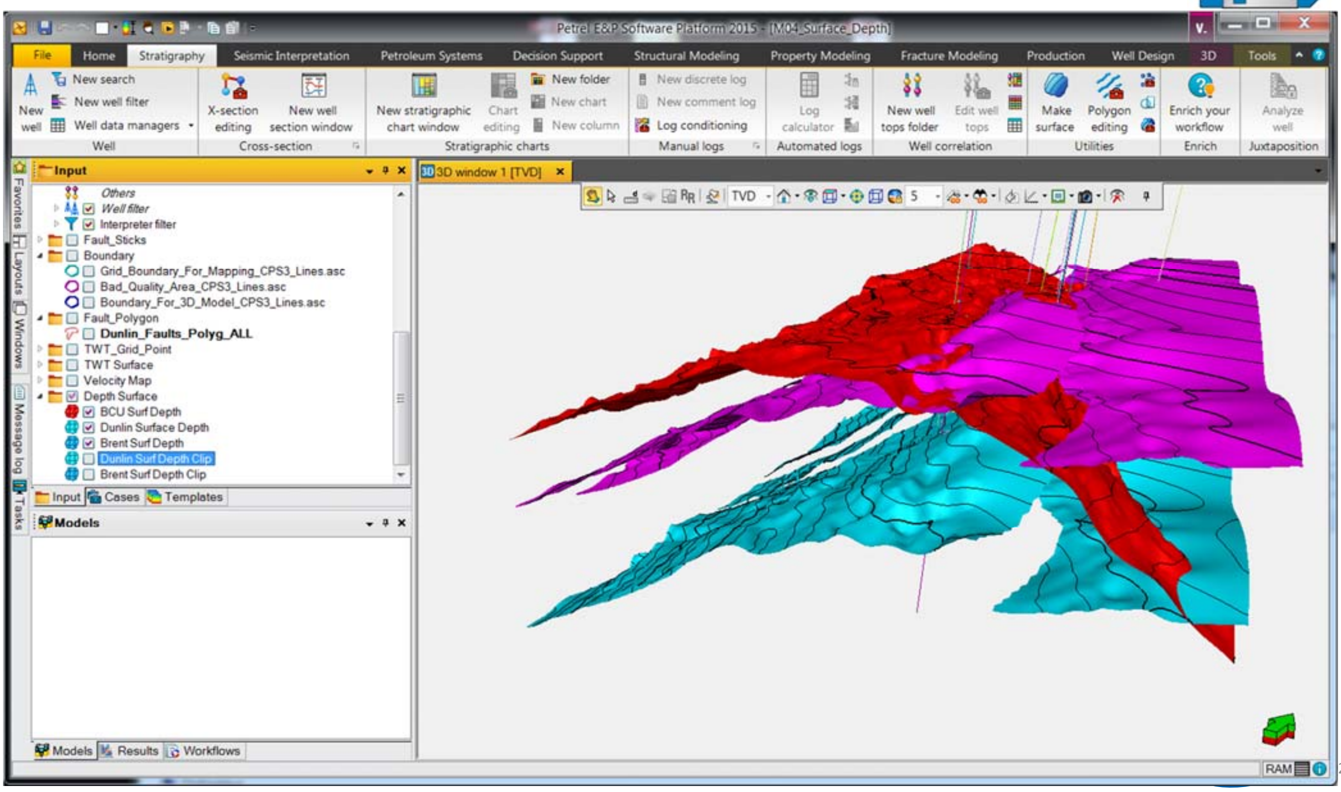
Clip Brent above BCU

- **Copy/Paste**
  - Copy/Paste the Computed Surface and rename as Brent Surface Depth
  - Copy/Paste the Brent Surface Depth as Brent Surface Depth Clip
  - Copy/Paste the Dunlin Surface Depth as Dunlin Surface Depth Clip
  - Select Brent Surface Depth Clip
    - Right click and select “Settings”, “Operations” option
    - Select “Eliminate where”, “Z > Surface (x,y)” (A)
    - Set “BCU Surf Depth” surface as reference surface (B) and press “Run” (C). The surface is now properly truncated
  - Redo with Dunlin Surface Depth Clip





M04_Surface_Depth



From seismic to surface modeling

- **Surface quality mostly depends on:**
  - Seismic quality
    - Resolution
    - Number of in-lines and cross-lines
    - Interferences that may occur along faults and edges
  - Seismic interpretation
    - Picking
    - Auto-tracking
    - Data processing
  - Accuracy in surface editing
    - Removing problematic/dubious points and artifacts
- **Surface operations can be:**
  - Eliminating part of a surface:
    - Trimming inside/outside defined polygon
    - Clipping above/below defined surface
    - Smoothing
- **Keep as much information (points) as possible**
  - If part of the surface to be removed seems too important, double check interpreted horizons with the geophysicist.

Structural modeling Hands-on

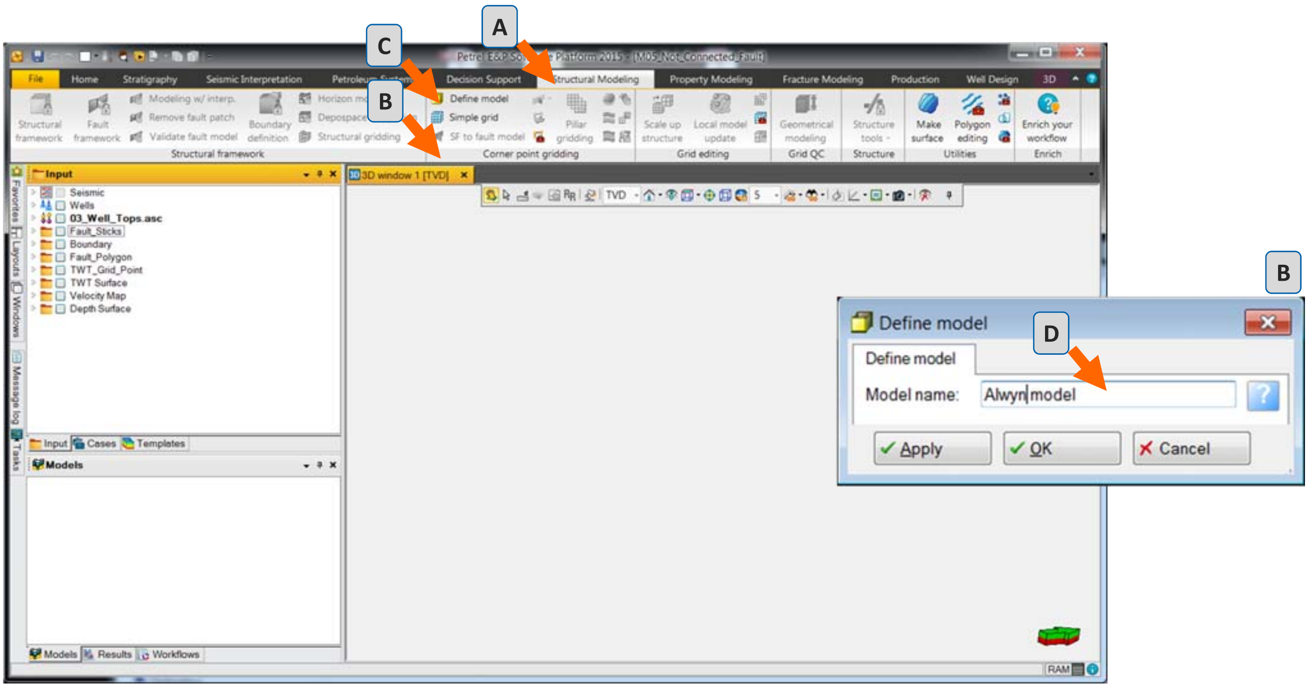
→ Hands-on practice HOP #1 on Appendix documents: perform manual structural interpretation

→ Back to Petrel after exercise

M04_Surface_Depth

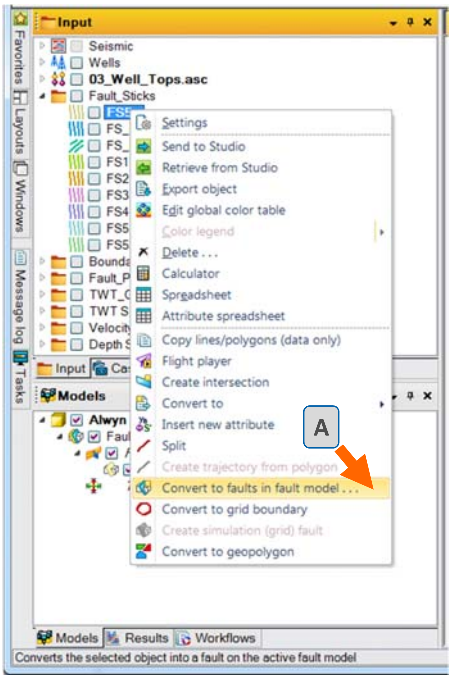
Create a Model

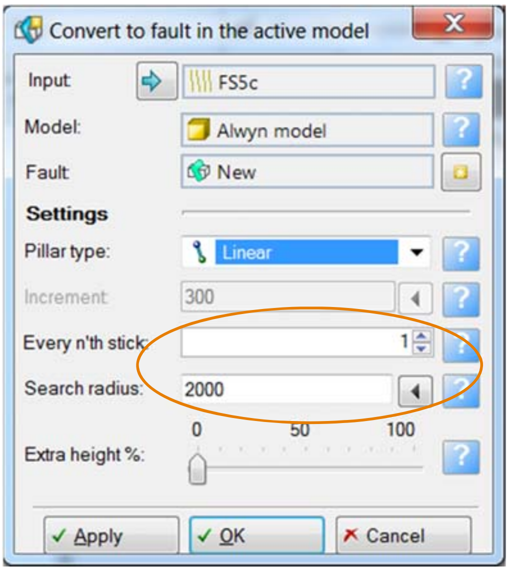
- **Create a Model**
  - In Ribbon select “Structural modeling” (A) and in “Corner point gridding area (B), Define Model (C)
  - “Alwyn_model” (D)



Create fault from sticks

- **From sticks to fault**
  - Develop and select one fault, and use the right click to “Convert fault in fault model”
  - Type in 1 (for every n’th stick) and 2000 (for search radius)
  - Apply the same procedure for the following faults

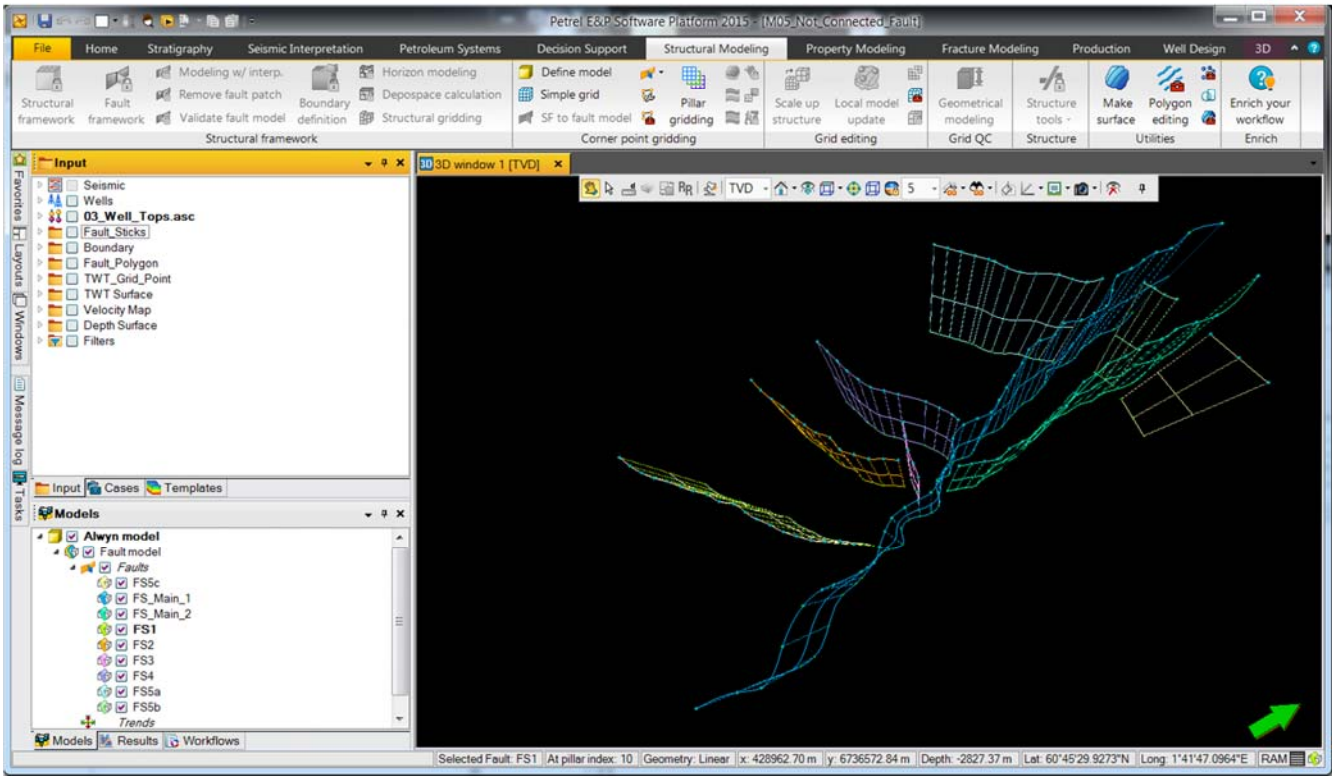




Type in 1 and 2000 for conversion values

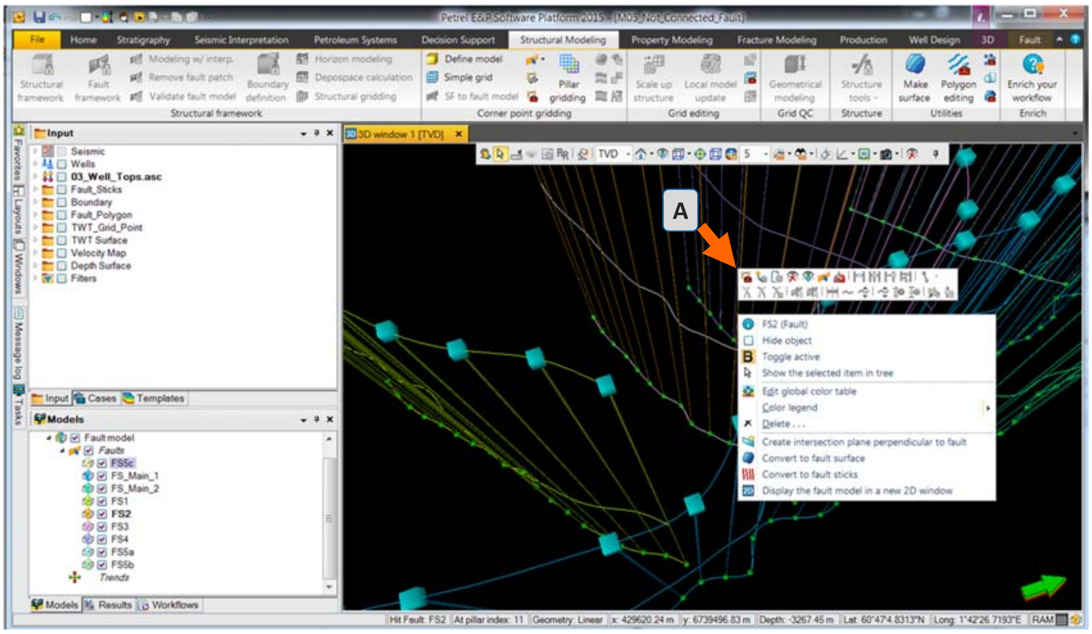
…/…

M05_Not_Connected_Fault



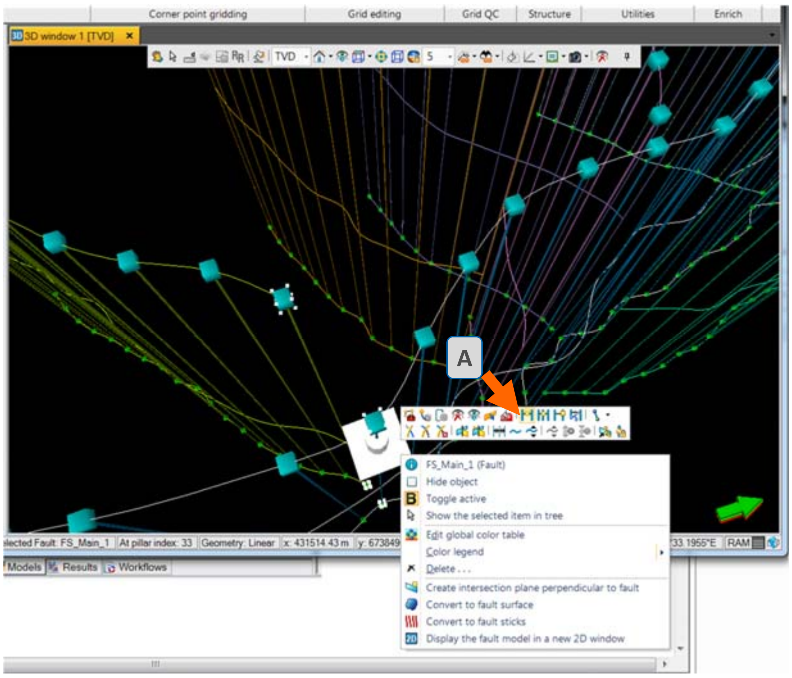
Fault network refining

- **Connecting faults**
  - Select one fault and use the right click to see the fault menu
  - Click on icon (A) to edit the fault model

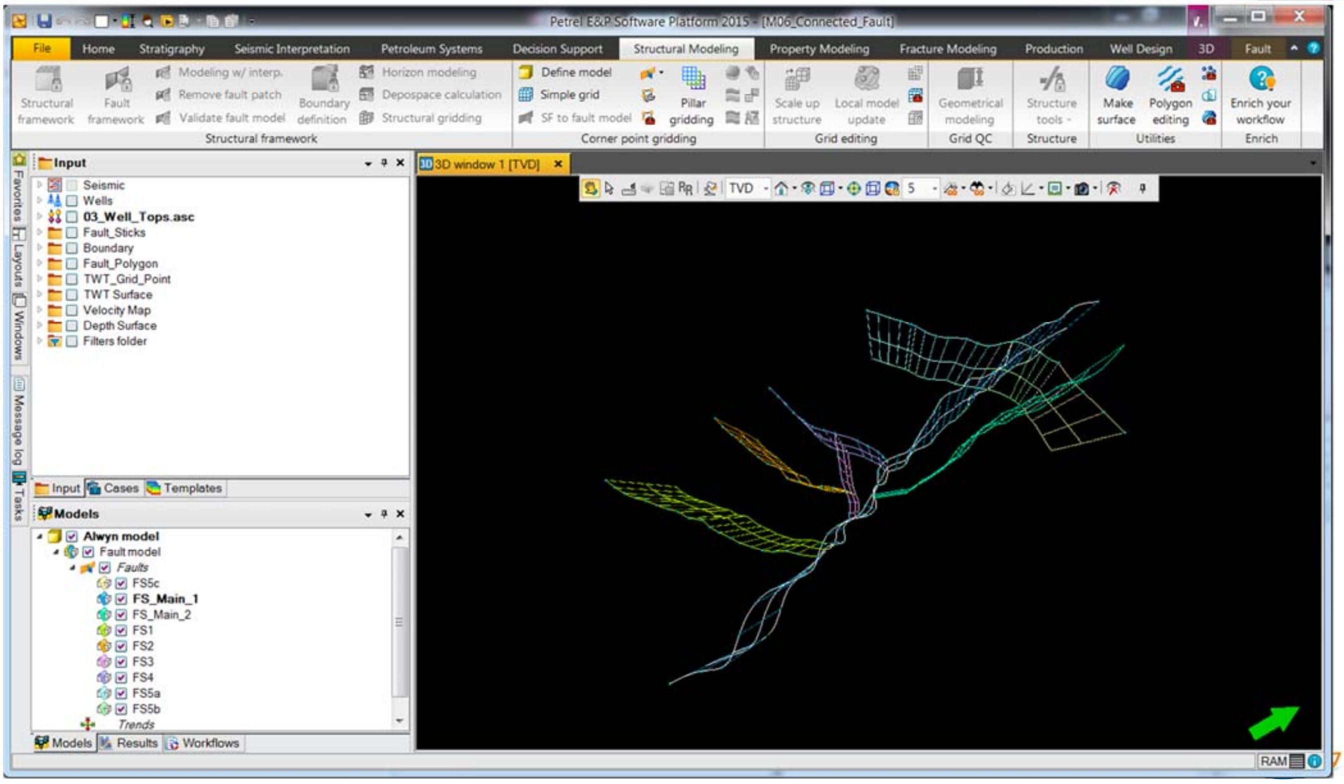


Fault network refining

- **Connecting faults**
  - Select two pillars to connects and right click on icon connect (A) 
  - Choose OK (B)

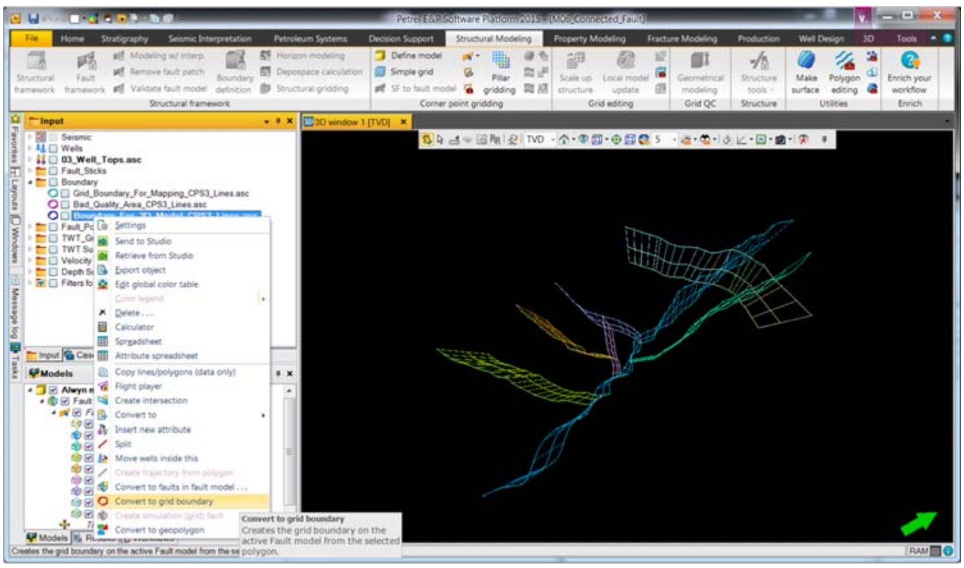


M06_Connected_Fault



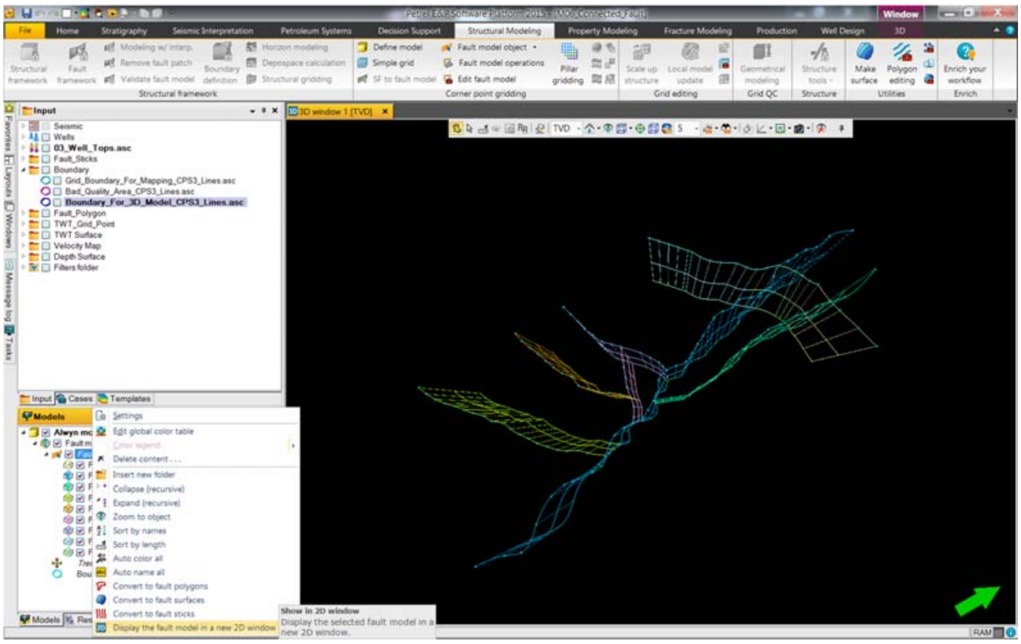
Pillar gridding

- **Build the fault network grid**
  - Select the boundary for the 3D model: “ Boundary_For_3D_Model_CPS3_Lines.asc”
  - Right click and “Convert to grid boundary”



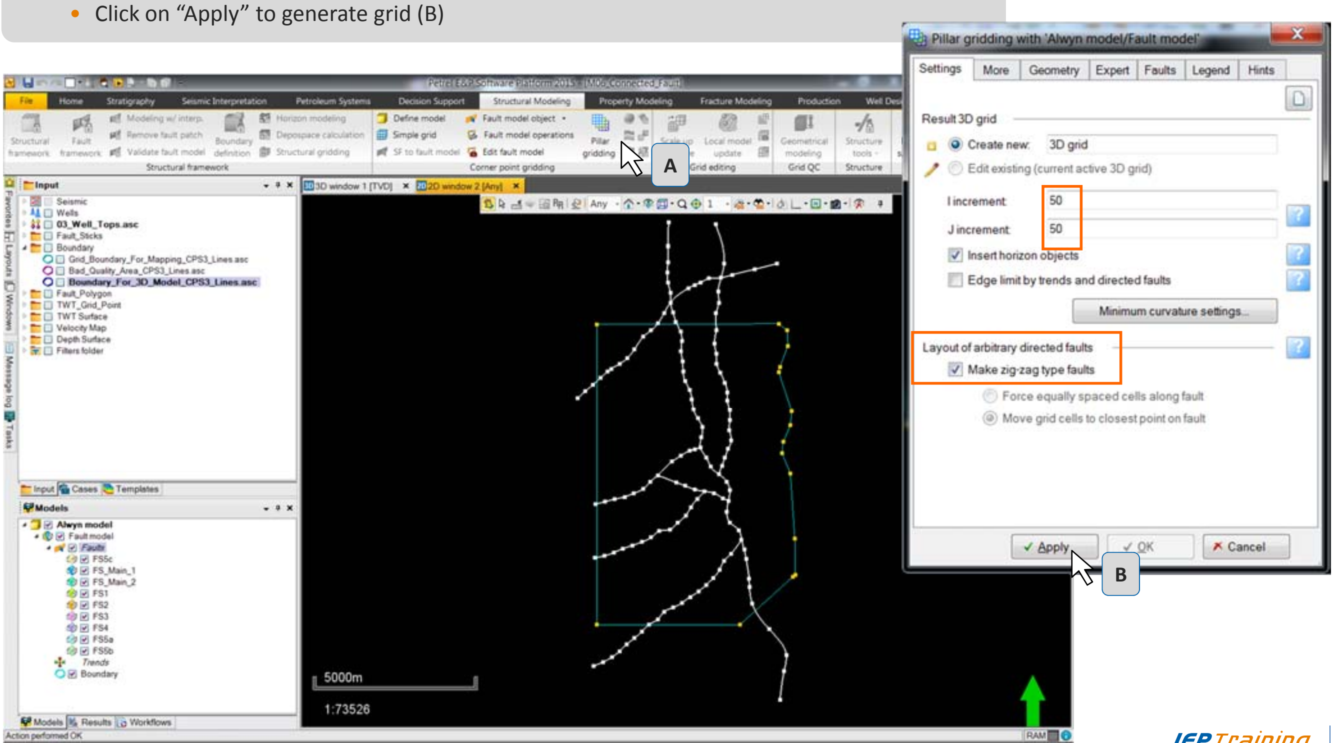
Pillar gridding

- **Build the fault network grid**
  - In Models panel select Faults → right click and "Display the fault model in a New 2D window"



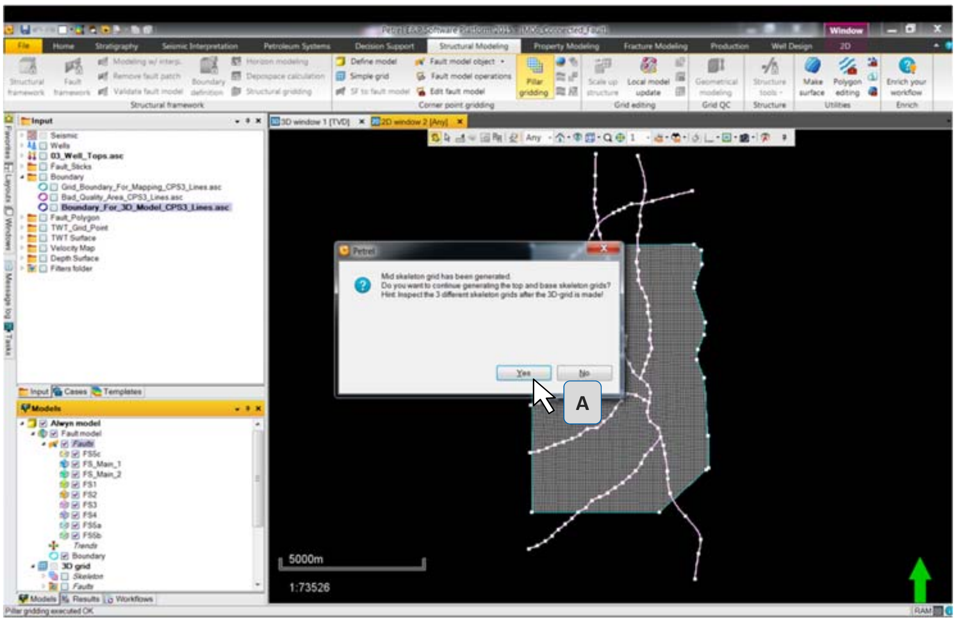
Pillar gridding

- **Build the fault network grid**
  - Adjust the zoom
  - Click on "Pillar gridding" (A), type 50*50 increment and tick the "Make zigzag fault" option
  - Click on "Apply" to generate grid (B)



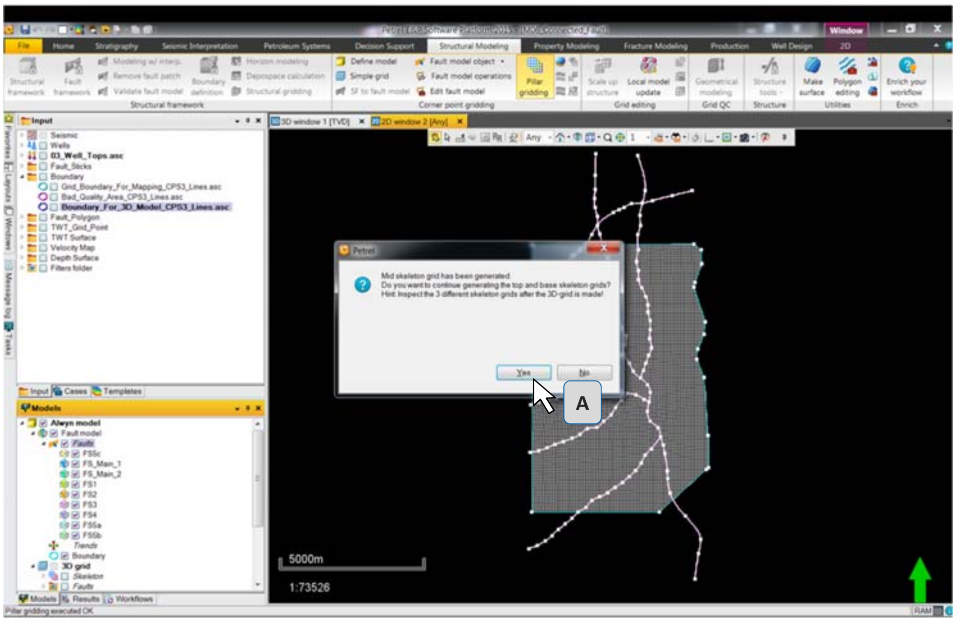
Pillar gridding

- **Build the fault network grid**
  - Yes (A)



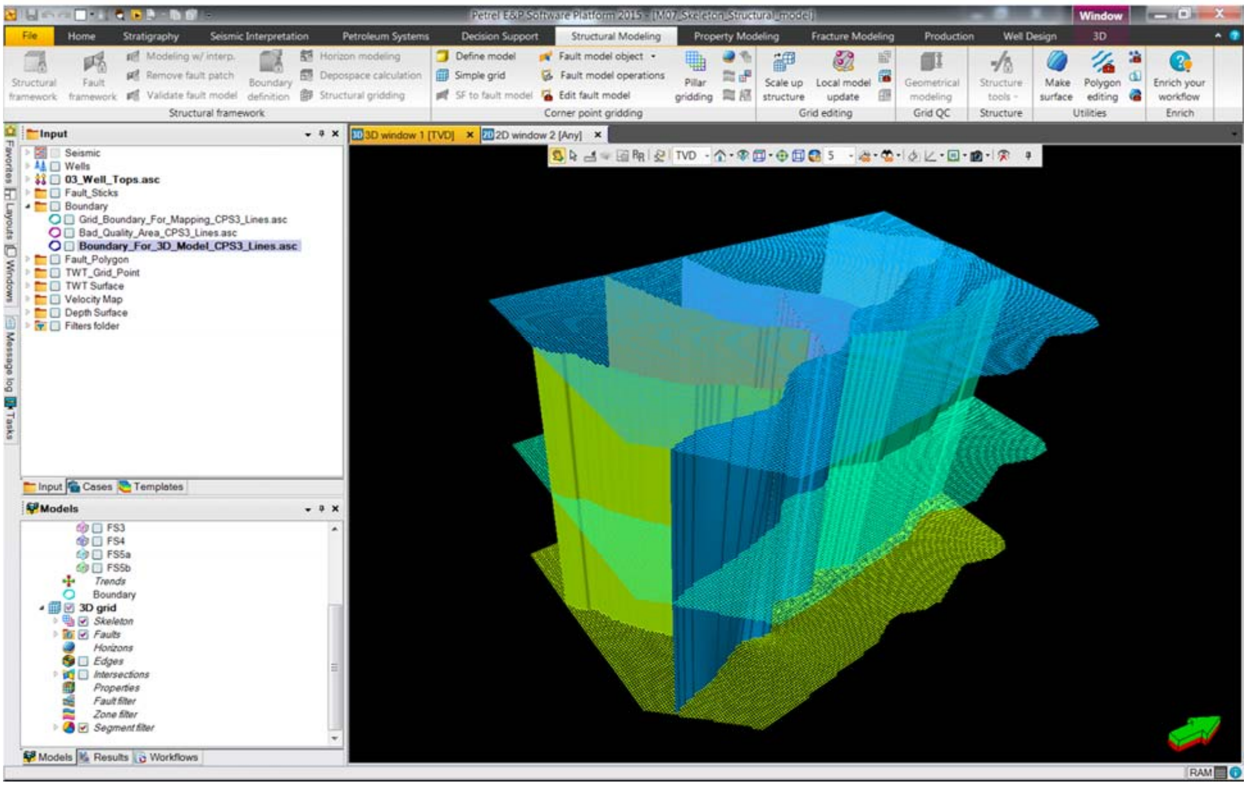
Pillar gridding

- **Build the fault network grid**
  - Active 2D window and select



M07_Skeleton_Structural_model

- **Visualize the structural model**
  - Select a 3D window and In "Model" tab click on "Skeleton"
  - Select "Faults"
  - Use the "Segment filter" option in "3D grid" to select the model compartments



Stratigraphic modeling Hands-on

Hands-on practice HOP #2 on Appendix documents

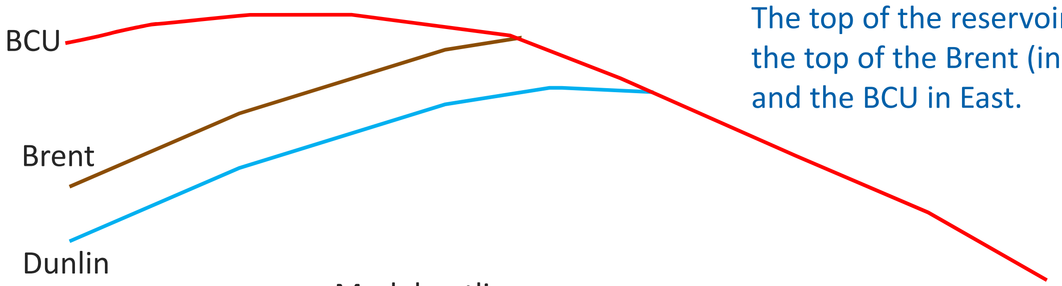
→ Insert a well section (correlation)

→ Interpret RFT plots

→ Back to Petrel after exercise

M07_Skeleton_Structural_Model

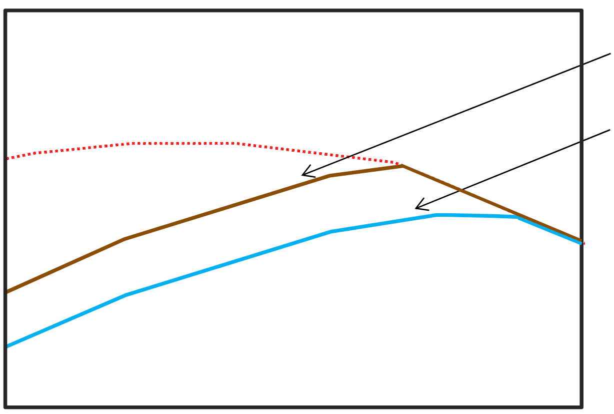
Create Top and Base horizons for the model



Warning

The top of the reservoir model is, the top of the Brent (in the west) and the BCU in East.

Model outline



Horizon_top_Model = min(BCU,Brent)

Horizon_top_Model = min(BCU,Brent)

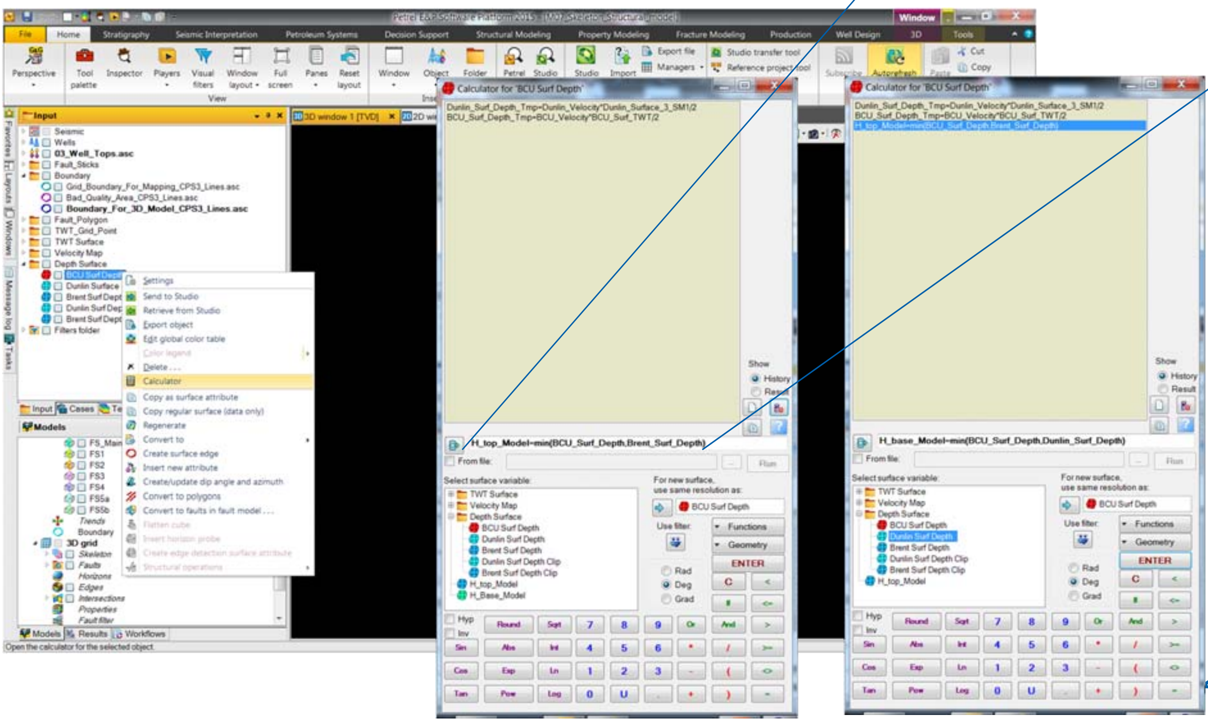
Modeled surfaces need to be bounded (closed)

Only the Brent is modeled, not the BCU

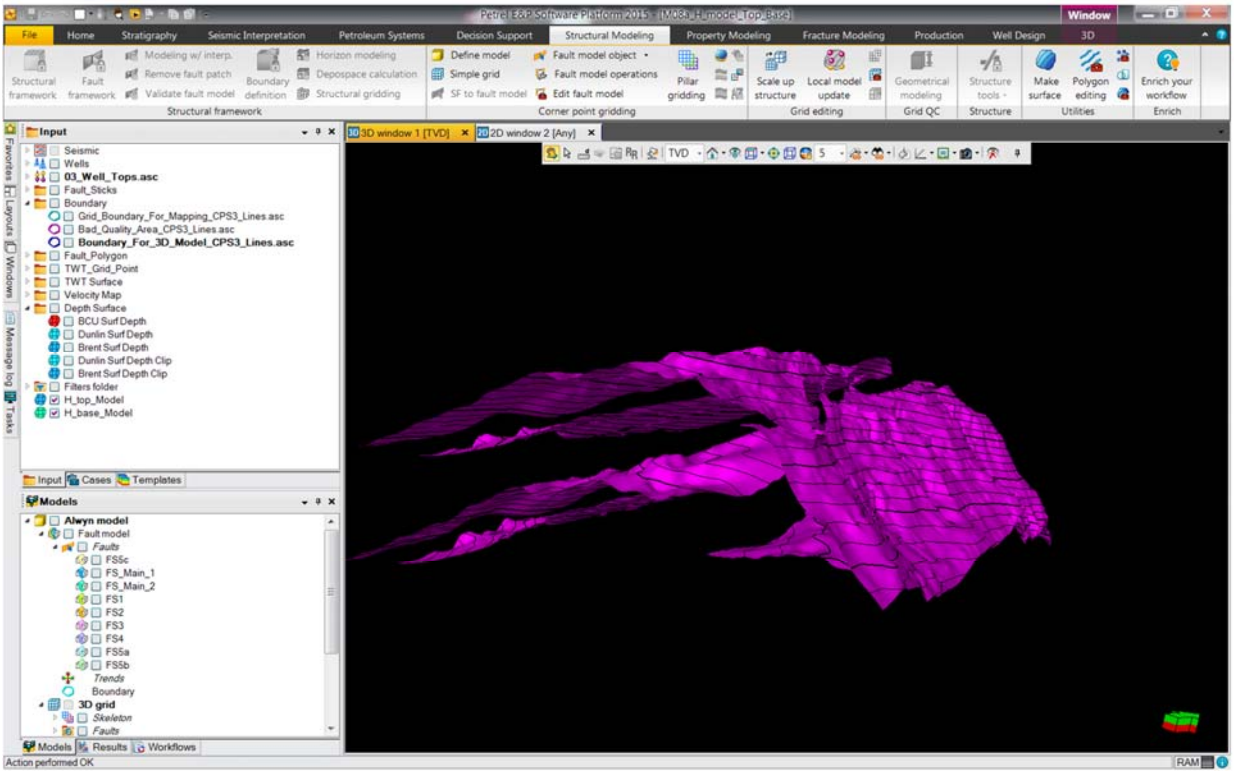
Create Top and Base horizons for model

- **Select one surface** – Right click and calculator
- **Enter formula**
  - H top_Model = min(BCU_Surf_Depth,Brent_Surf_Depth) → *Enter*
  - H_base_Model = min(BCU_Surf_Depth,Dunlin_Surf_Depth) → *Enter*

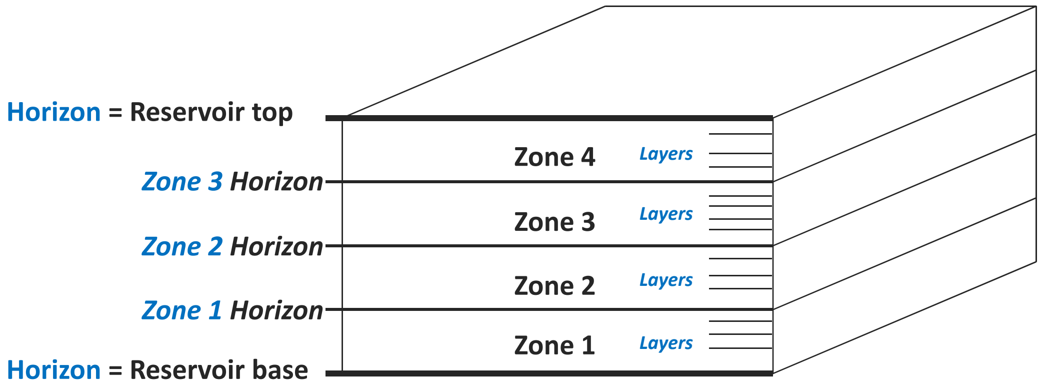
comma



M08a_H_model_Top_Base

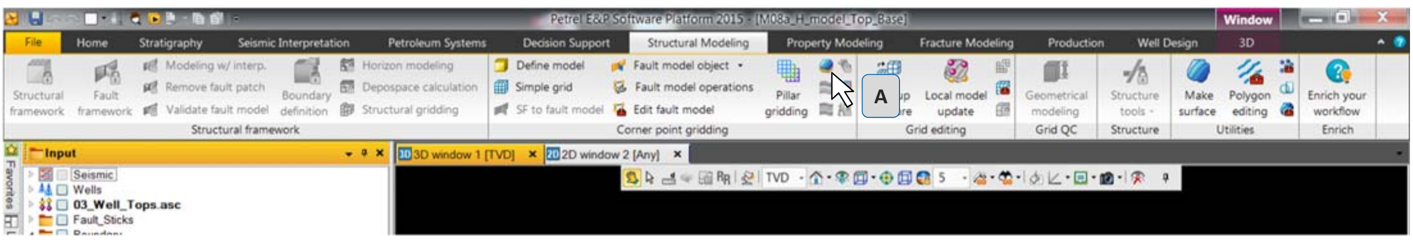


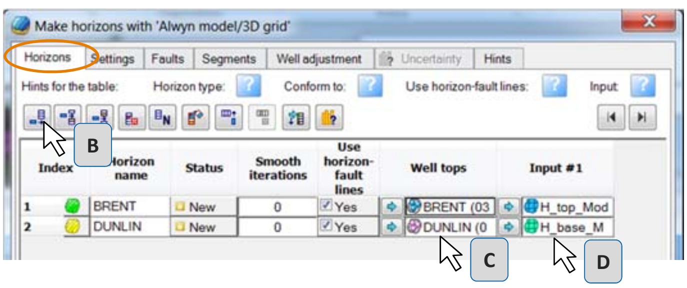
Understand Petrel’s vocabulary

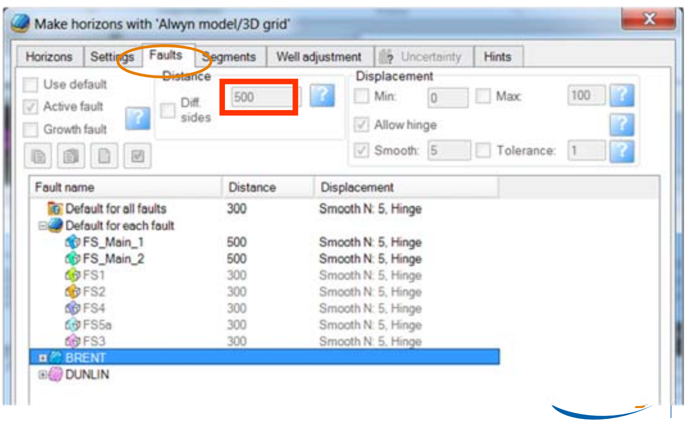


Make horizons

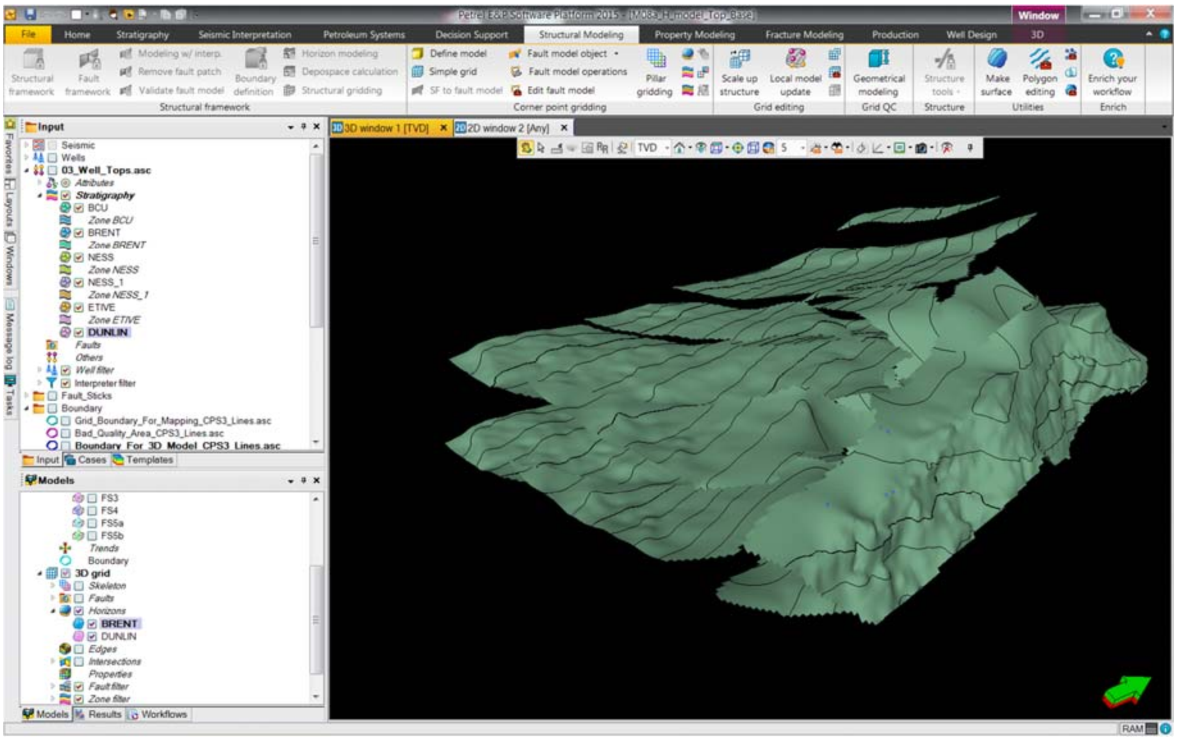
- **Create reservoir horizons**
  - Select “Make horizon” (A)
  - Click on “Append item in the table” icon to display the number of horizons (B)
  - Import both Well tops (C) with blue arrows and Horizons (Top and Base) for the model <u>in depth</u> (D)
  - In “Faults” tab, change “Distance” parameter (i.e. fault plane extension in m) to “500” for the two major faults on both horizons, keep “300” for minor faults (unselect “Use default” to adjust values for each fault)





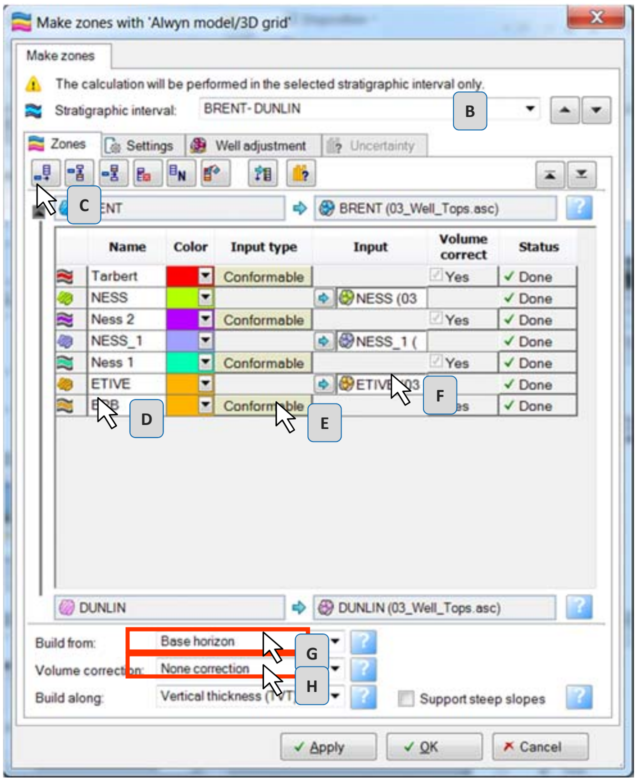


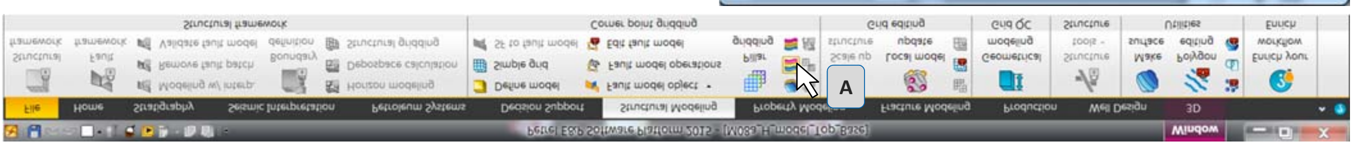
Make horizons – M08b_Make_H



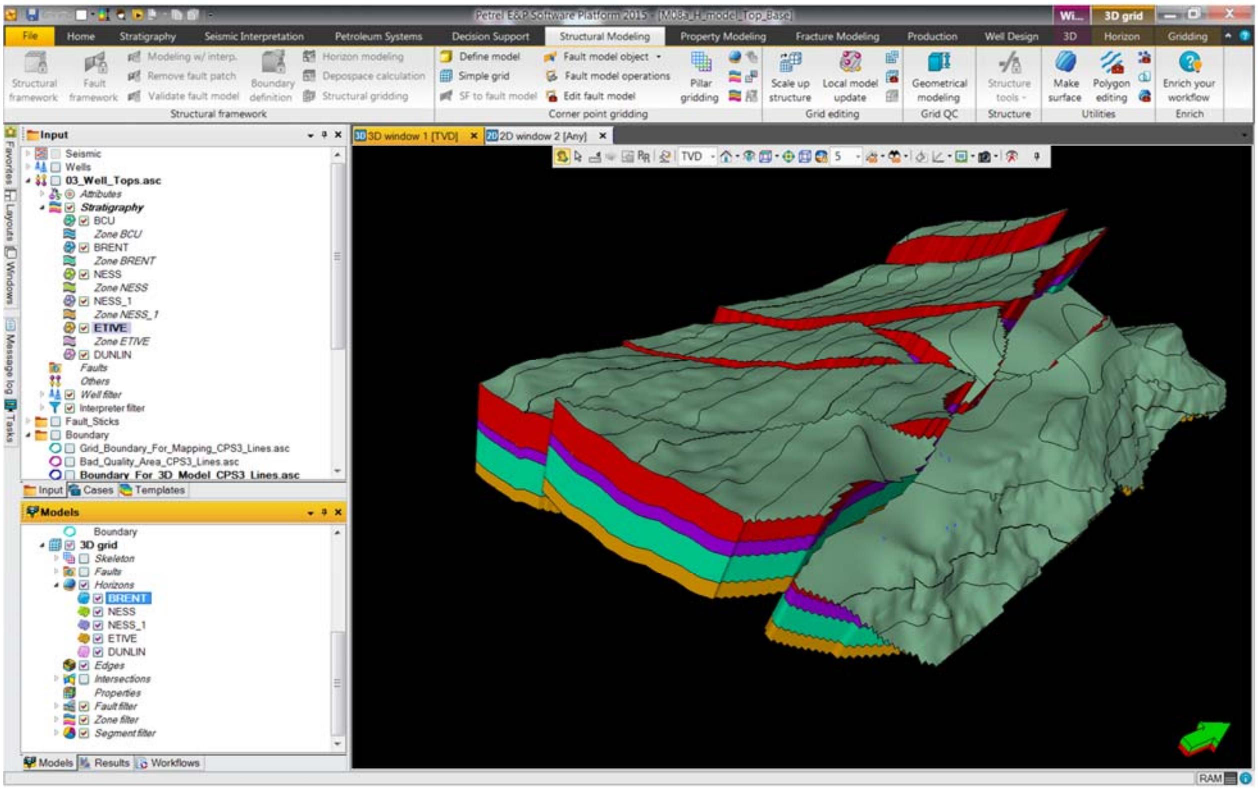
Make zones

- **Create reservoir layering between horizons**
  - Select "Make zones (A)
  - Select the interval to be zoned (B)
  - Click on the "Append item in table" icon to display the number of horizons (C)
  - Rename the zone and select the horizon type in column 3 (D & E)
  - Import the well tops in depth with blue arrows (F)
  - Select "Base Horizon" in "Build from" menu to specify the zoning from picked horizon (G)
  - Select "None correction" to represent BCU unconformity (H)



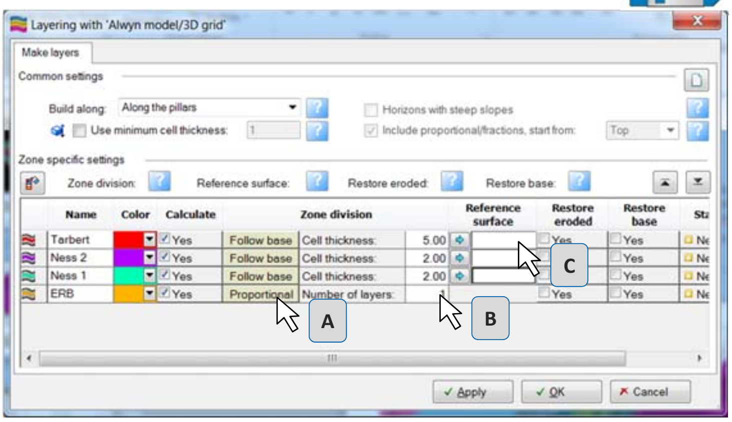


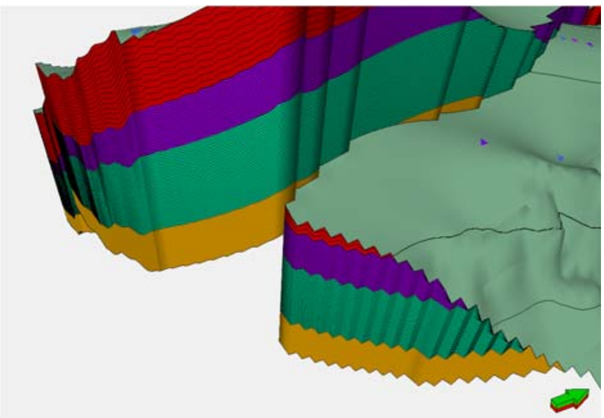
M08c_Make_Zone

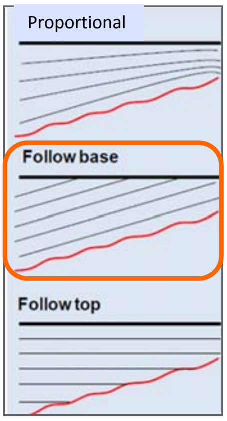


Layering – M08d_Layering

- **Create layering in previously created zones**
  - Select "Layering"
  - Select the division type (A) and number of layers (or thickness) for each zone (B) according to the stratigraphic model. Use "Follow base" to represent BCU unc
  - Use respectively 5, 2, 2 and 1 layer thickness in each zone
  - Note: Do not specify any "Reference surface" trend (C)

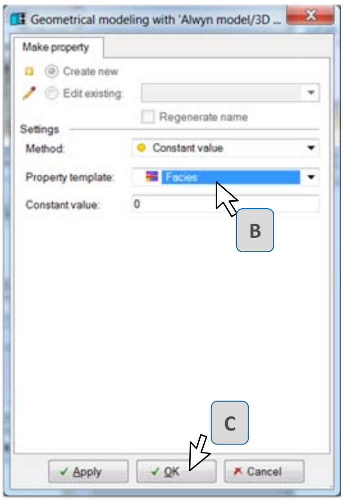


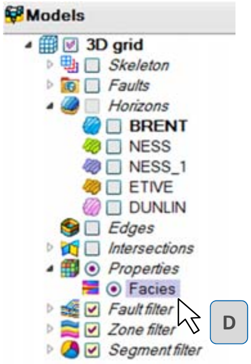


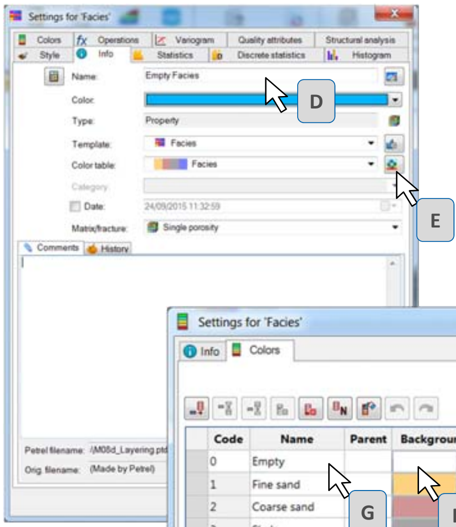


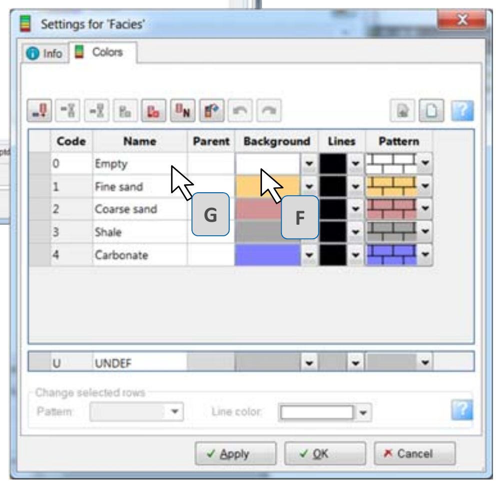
Create empty property model

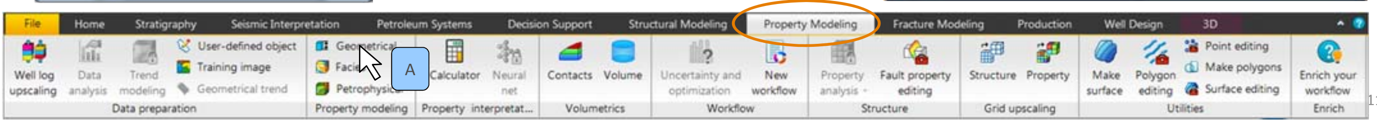
- **Visualize the empty model ➔ Create an "empty" property**
  - In "Property modeling", select "Geometrical modeling" (A).
  - Choose: Property template "Facies" (B) and OK (C)
  - In "3D grid", Select "Facies" and "Settings" (D)
  - Click on the "Popos up global settings" icon (E)
  - Click on (E) icon to change facies color (F) and name (G)





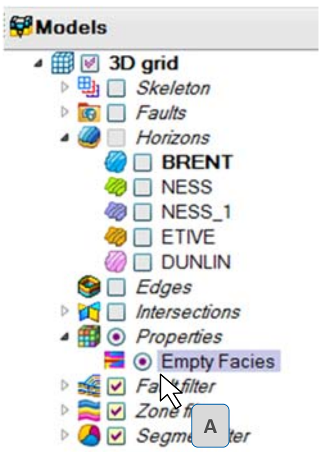


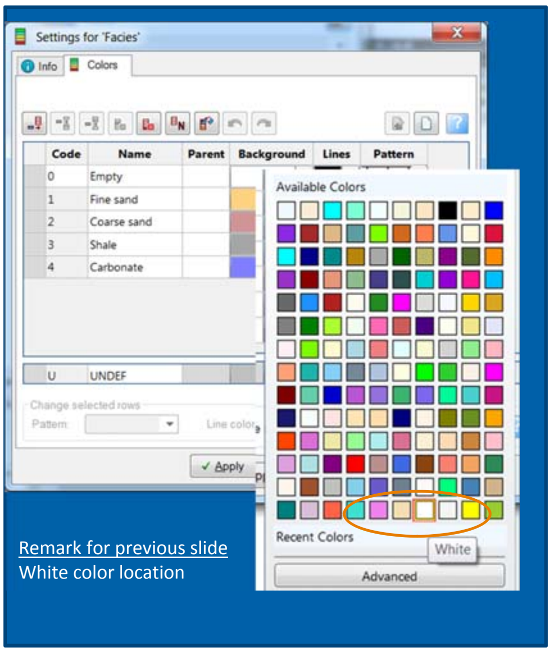


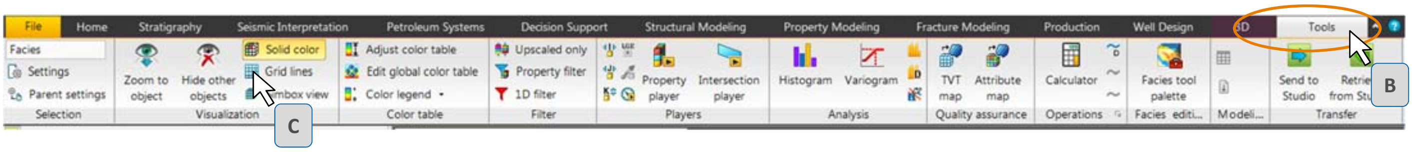


Display empty model

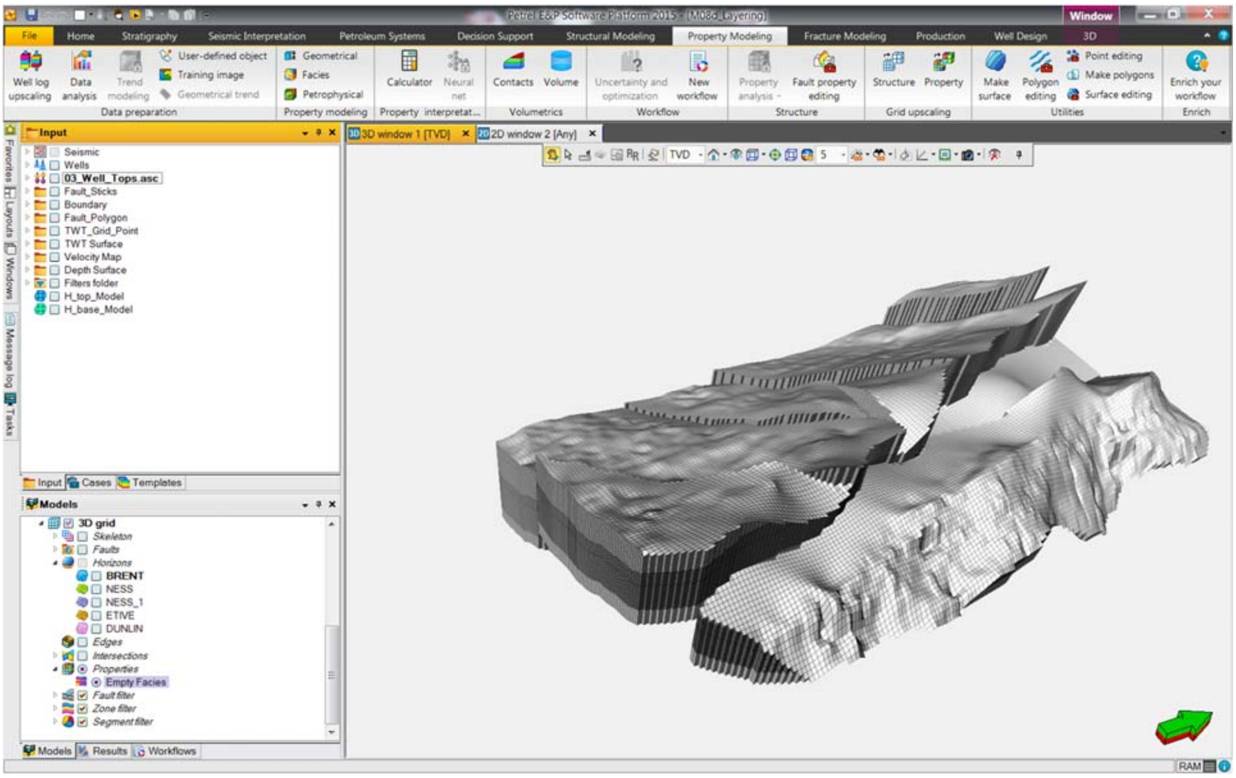
- **Display the Cellular model**
  - In the panel "Model" select Properties → "Empty Facies" (A).
  - In Ribbon select "Tools" (B)
  - Select grid line (C) or in 3D display window right click"





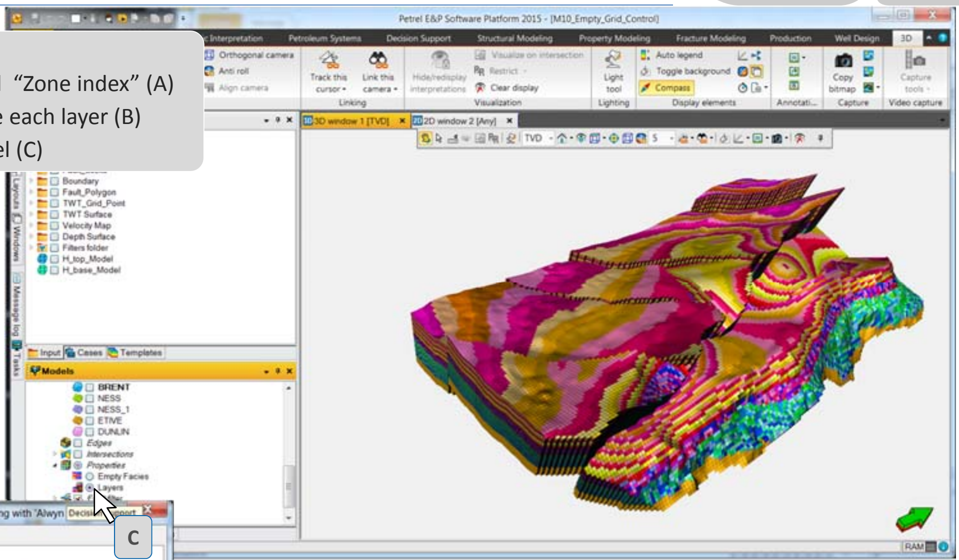


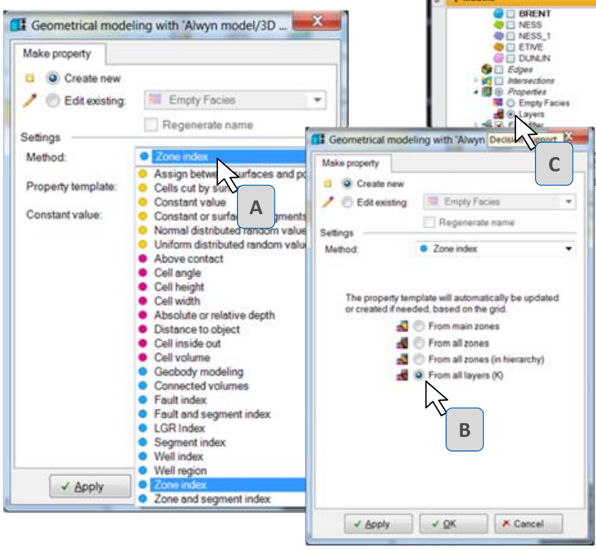
M09_Empty_Property



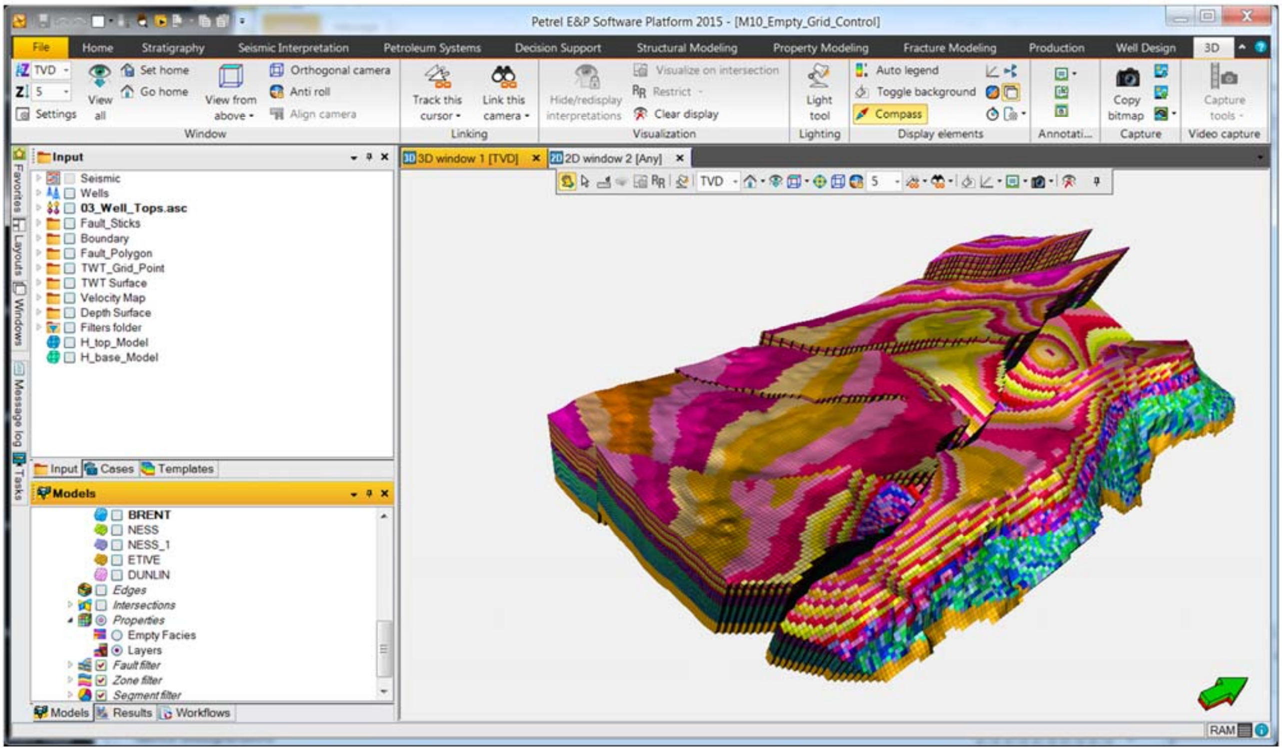
Generate geometrical properties

- **Zone index property**
  - Geometrical modeling → Method "Zone index" (A)
  - Select "From all layers (K)" to code each layer (B)
  - Select "Layers" in properties model (C)





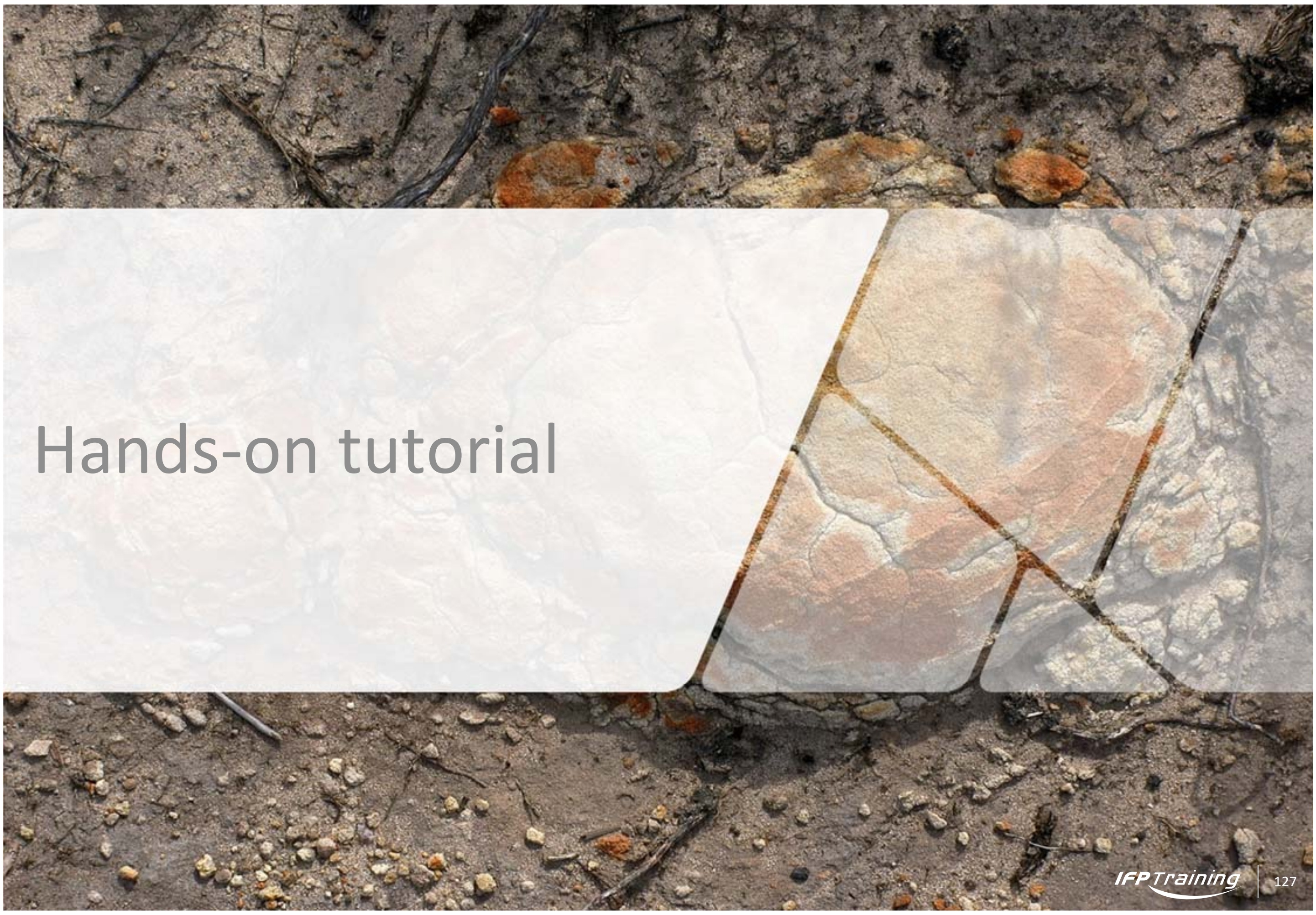
M10_Empty_Grid_Control



3. Rock Typing with Easy Trace©

Chapter 3 - Summary

- **Rock Typing *(EasyTrace©)***
  - Tutorial
    - Getting started with *EasyTrace©*
    - HOP objectives
  - Hands-on practice
    - Non-supervised approach
    - Supervised approach
    - Petrophysical calibration



Rock typing objectives - Summary

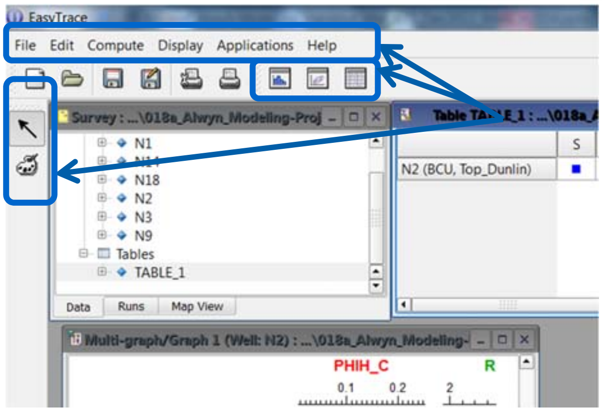
- **Getting started with *EasyTrace*©**
  - Use a dedicated software for rock typing
  - Use logs and integrated data
- **Non-supervised approach -** *Real case hands-on*
- **Supervised approach -** *Real case hands-on*
  - Understand mechanism of each approach
  - Choose suitable approach and cross results
- **Petrophysical calibration -** *Real case hands-on*

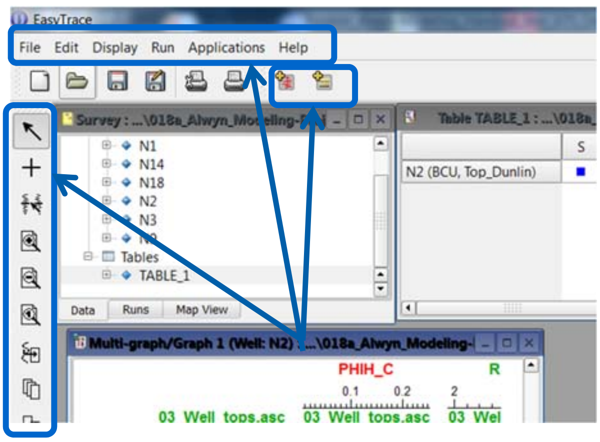
Getting started with EasyTrace©

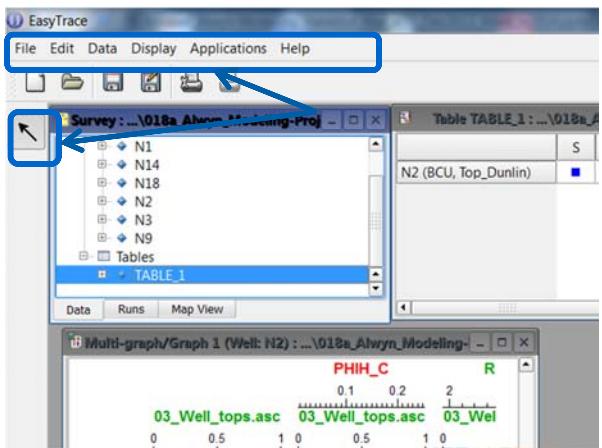
Part 3A

Contextual menu

Warning: *Contextual menu and tools bar Change according to the selected window*

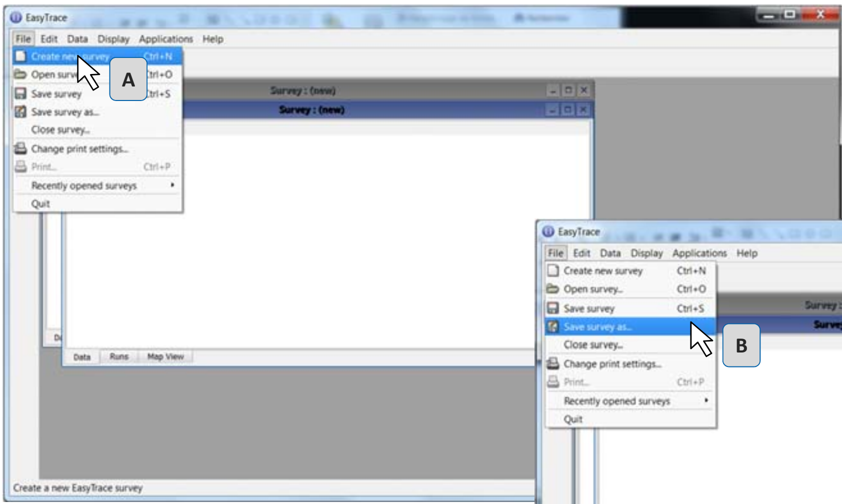


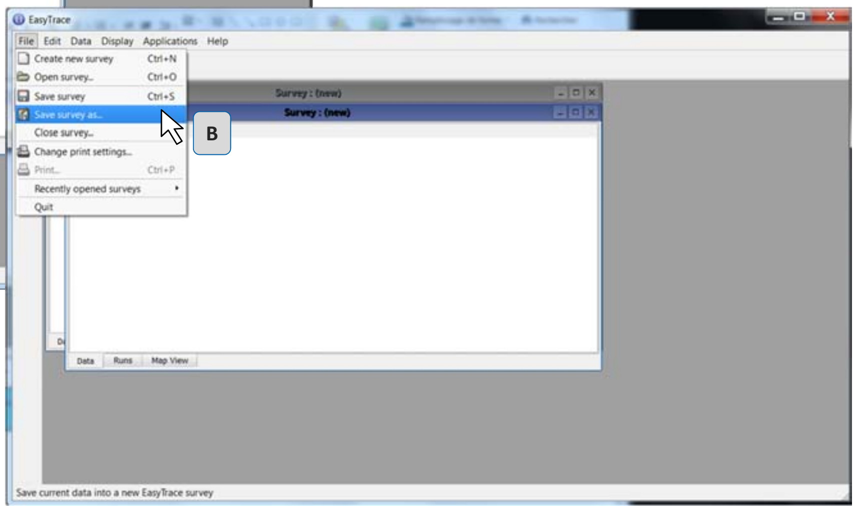




Create / Save survey

- File → Create new survey (A)
- File → Save survey as “EZT_Alwyn” (B)



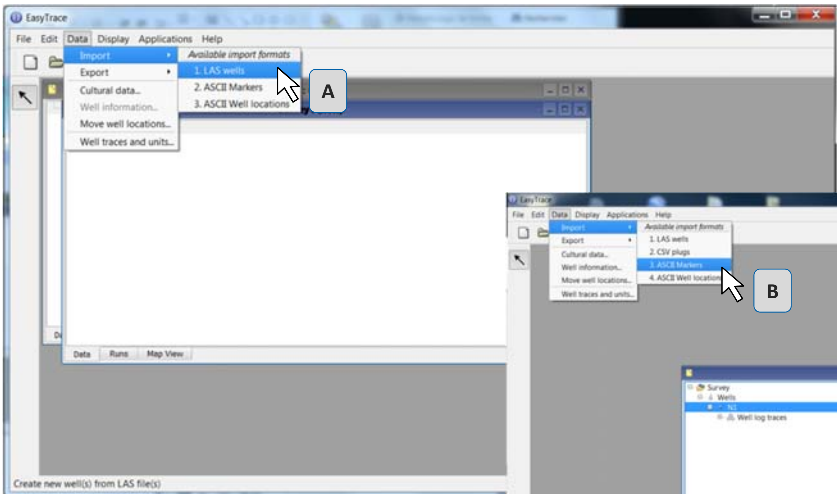


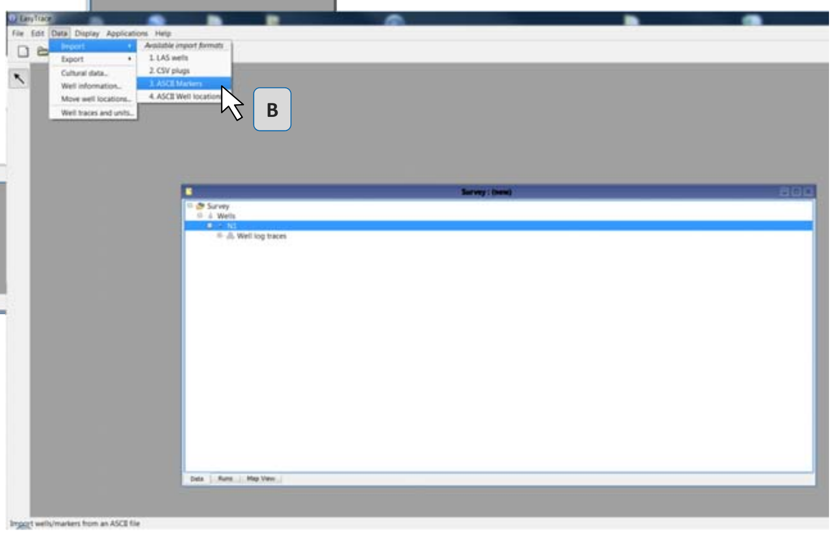
Import well logs and markers

- Import Well logs: Data → Import → LAS wells (A)
- Import markers: Data → Import → ASCII Markers (B)

Use “01_Getting_Started_EZT_Data” for first training

Use “ 02_Well_Log_LAS” and “03_Well_tops.asc” and “Markers. prn” for project data loading

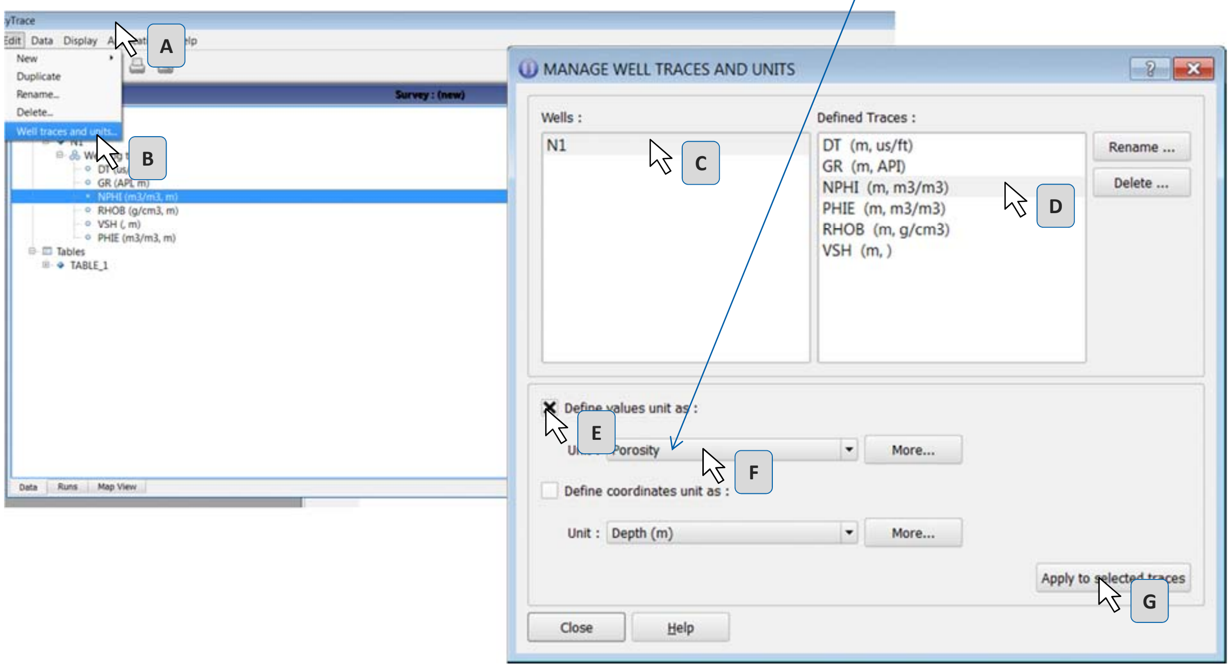




Activate abacus

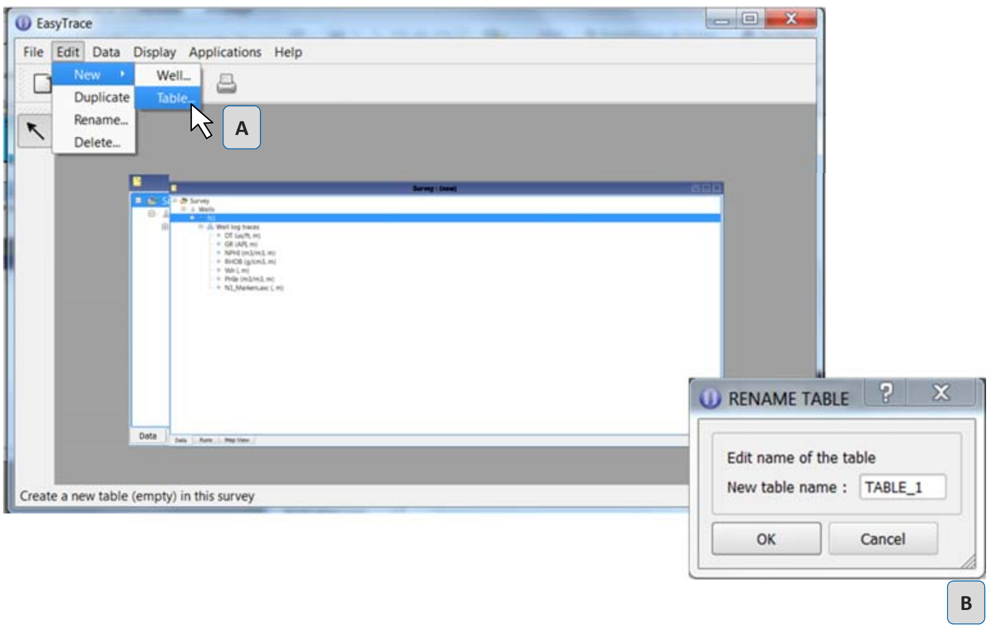
- To activate the conventional abacus, change NPHI unit from “anonymous” to “Porosity”
- Select the survey window (A)
- Edit – Well traces and units (B)
- Select well (C), Select NPHI log (D)
- Select define value unit as (E)
- Select Porosity (F) and apply to selected zone (G).
- Close.

Porosity but NOT “Porosity %”



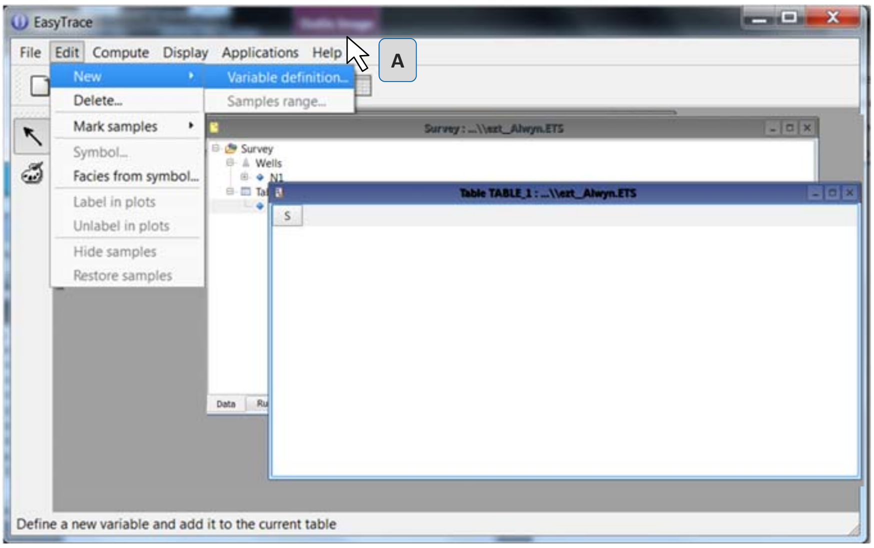
Create a table

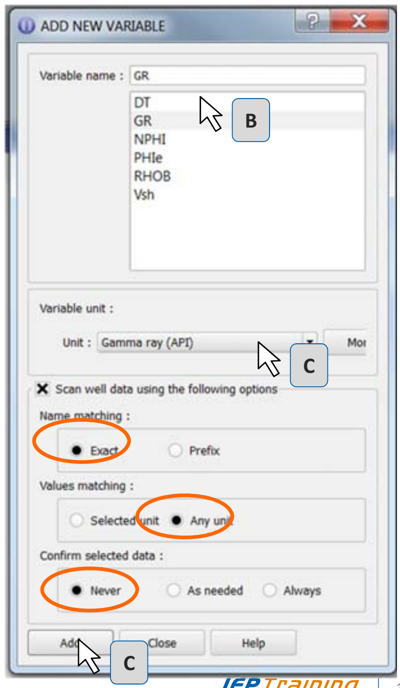
- Edit → New → Table (A)
- Type in the new table name (B)



Assign logs to a table

- Edit → New→ Variable definition (A)
- Select GR (B) and click on “Add” (C)
- Apply the same procedure for RHOB log.
- For NPHI do the same but change the unit as “Porosity”

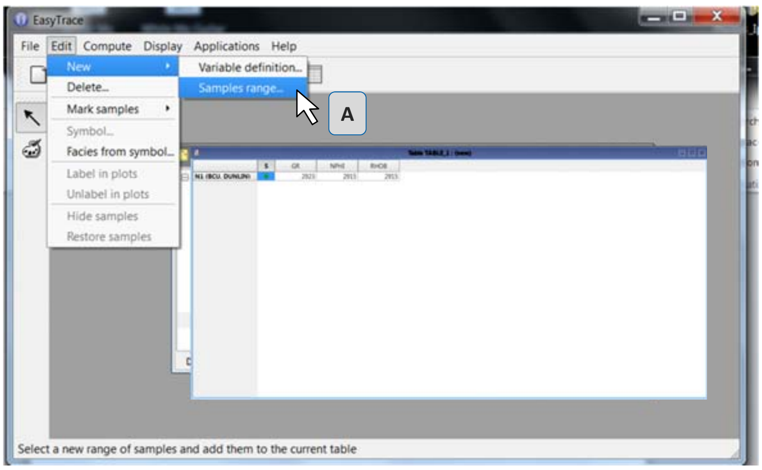




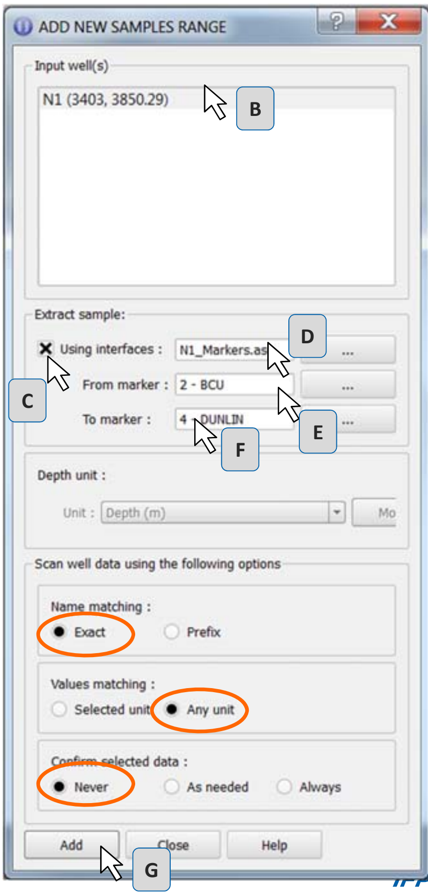
Note: always select the following options →

Assign wells to a table

- Edit → New → Samples range (A)
- Select the well N1 (B), tick “Using interfaces” (C), call N1_markers.asc file in window (D), BCU in (E) and DUNLINin (F)
- Click on “Add” (G) and “Close”

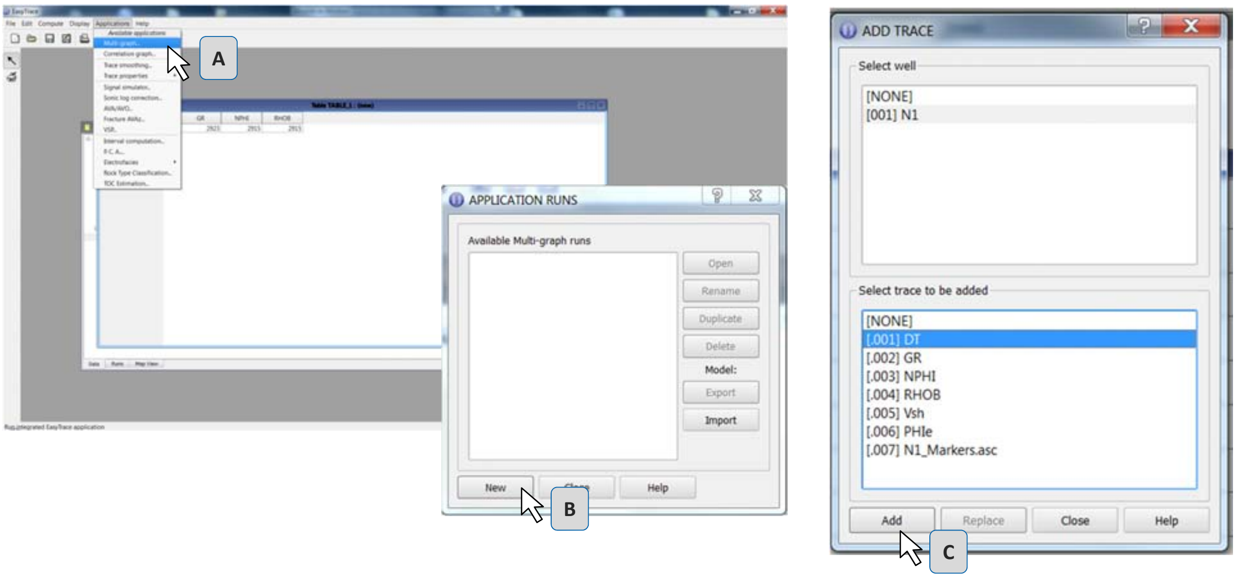


Note: always select the following options →



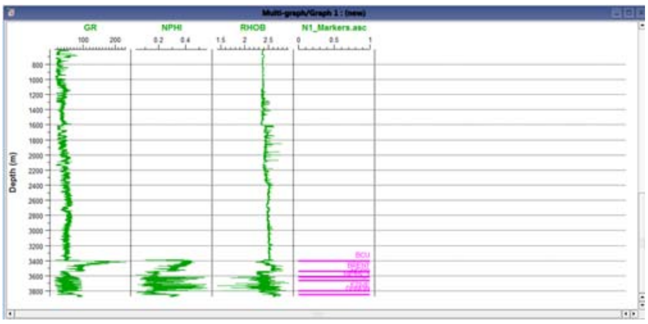
Create a synthetic log

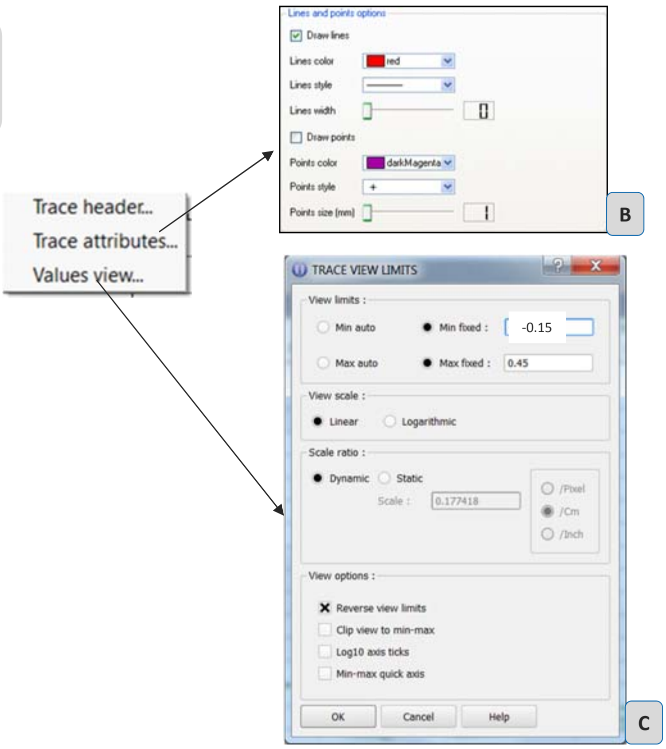
- Applications → Multi-graph (A)
- Click on “New” (B)
- Select the well N1 and logs
    - GR Click on “Add” (C)
    - NPHI Click on “Add” (C)
    - RHOB Click on “Add” (C)
    - N1_Markers.asc Click on “Add” (C)
- and “Close”

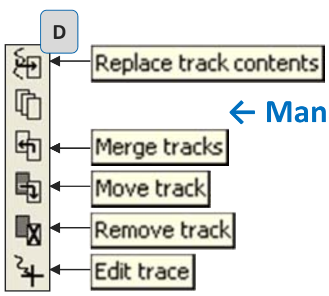


Visualize and manage colors, scale & traces

- Select the log name and click on right button (A)
- Adjust the color line and points by using “Trace attribute” (B)
- Adjust the scale by using “Values view” (C)
- Manage the track by using the tool bar located on the left side (D)







← **Managing track menu**

Proposed log scales

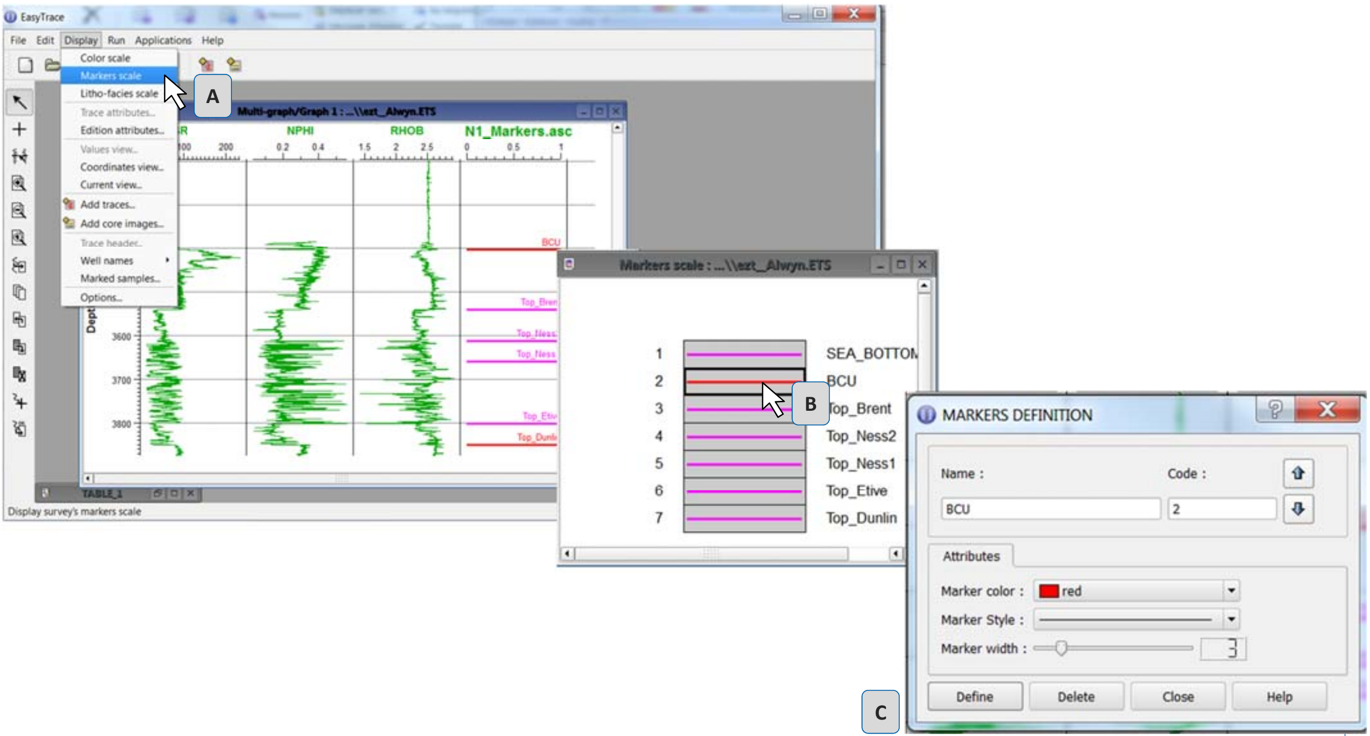
Limestone compatible scale →

GR: 0 → 200
NPHI: 0.45 → -0.15
RHOB: 1.95 → 2.95

Do not forget to Reverse view limits

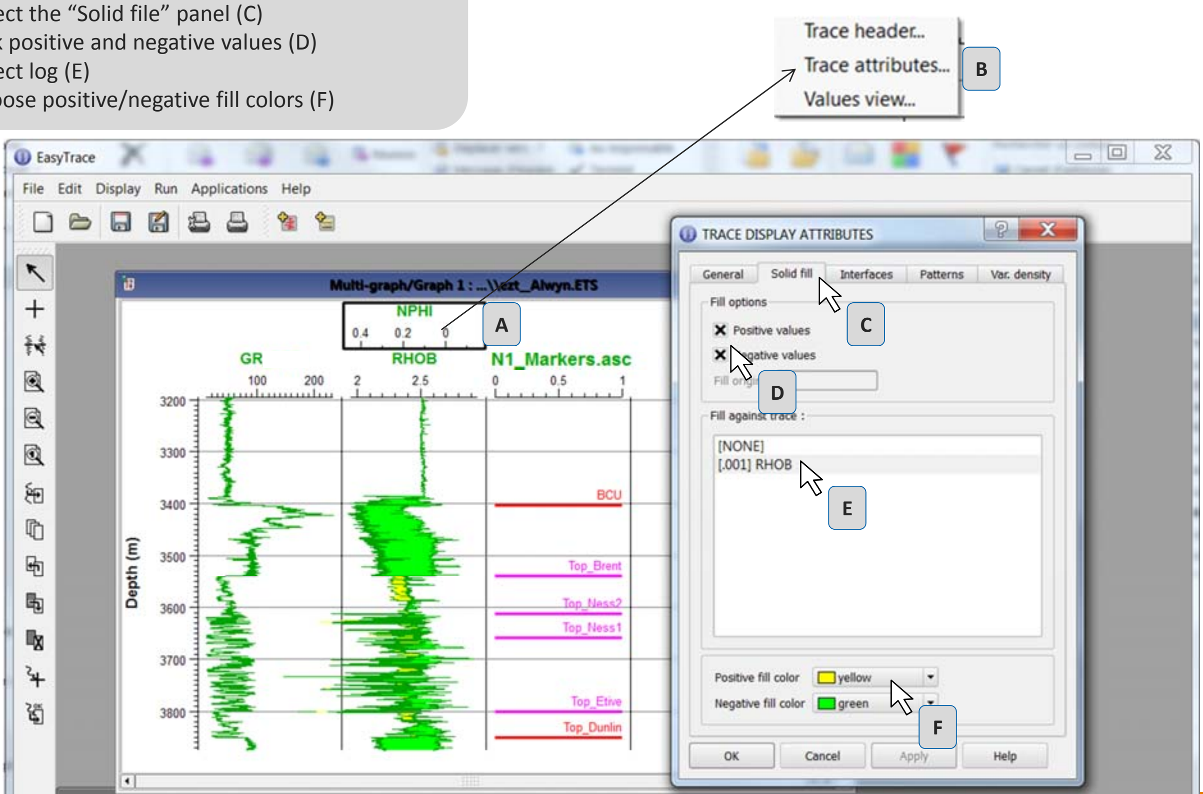
Markers color and size

- Adjust the markers color and size (A) and (B)
- Adjust the color line and points by using “Trace attribute” (B)
- Adjust the parameters on (C)

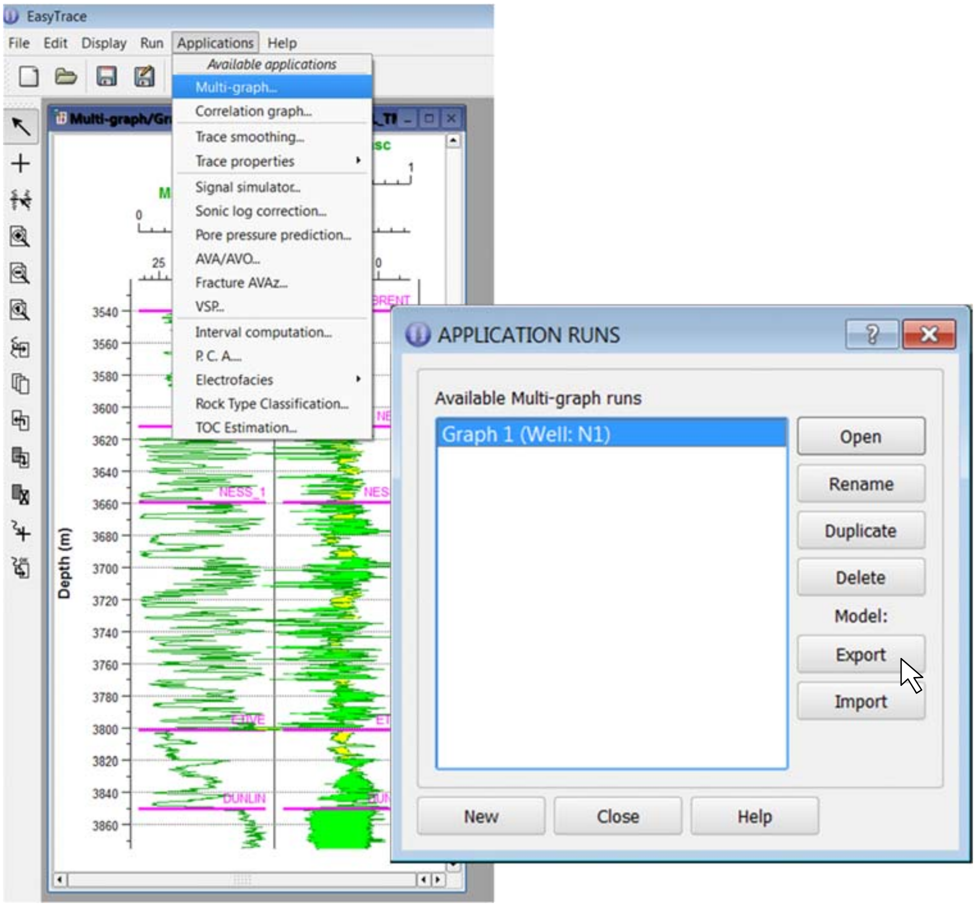


Color filling between logs

- Select the Header (A)
- Right click, choose Trace attributes (B)
- Select the “Solid file” panel (C)
- Tick positive and negative values (D)
- Select log (E)
- Choose positive/negative fill colors (F)

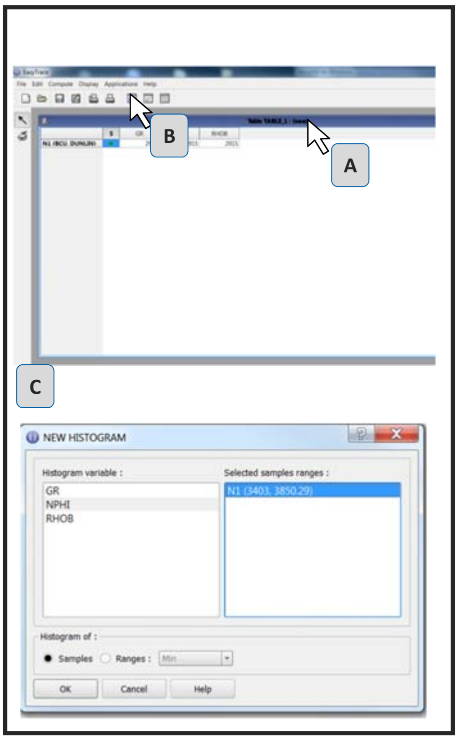


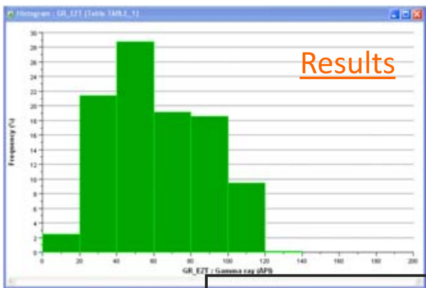
Export the Graph Template for Hands-on

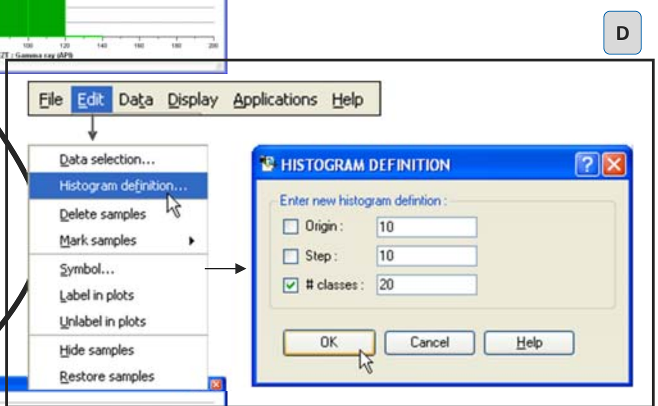


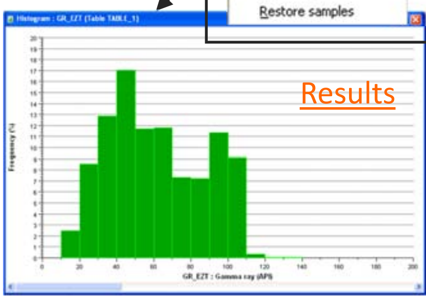
Generate histograms

- Activate the Table window (A)
- Display histogram (B)
- Select variable and sample range (well) (C)
- Change the data range/number of classes (D)



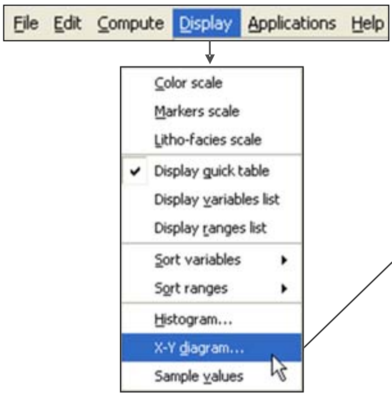




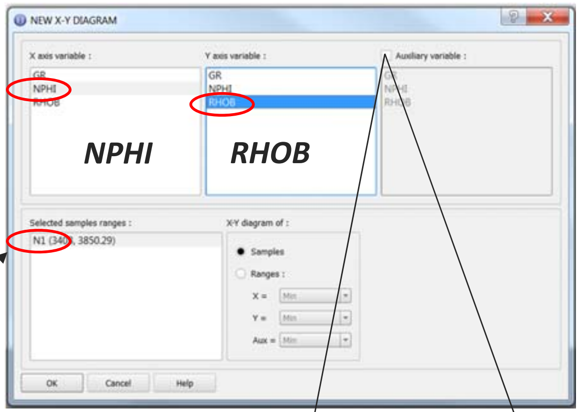


Generate cross-plots *(e.g. NPHI-RHOB)*

Create Cross-plots

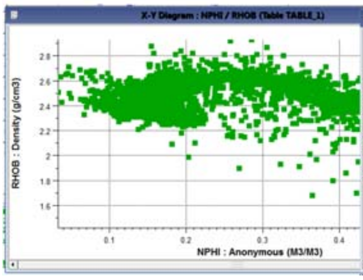


Select variables

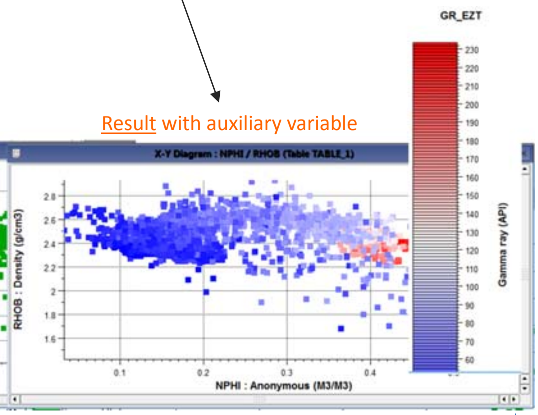


WARNING!
Do not select any "auxiliary variable", if you want to visualize electrofacies in a cross-plot

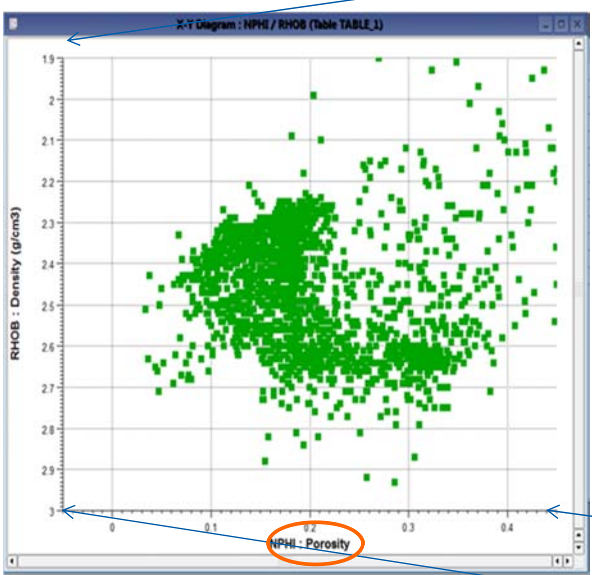
Result without auxiliary variable



Result with auxiliary variable



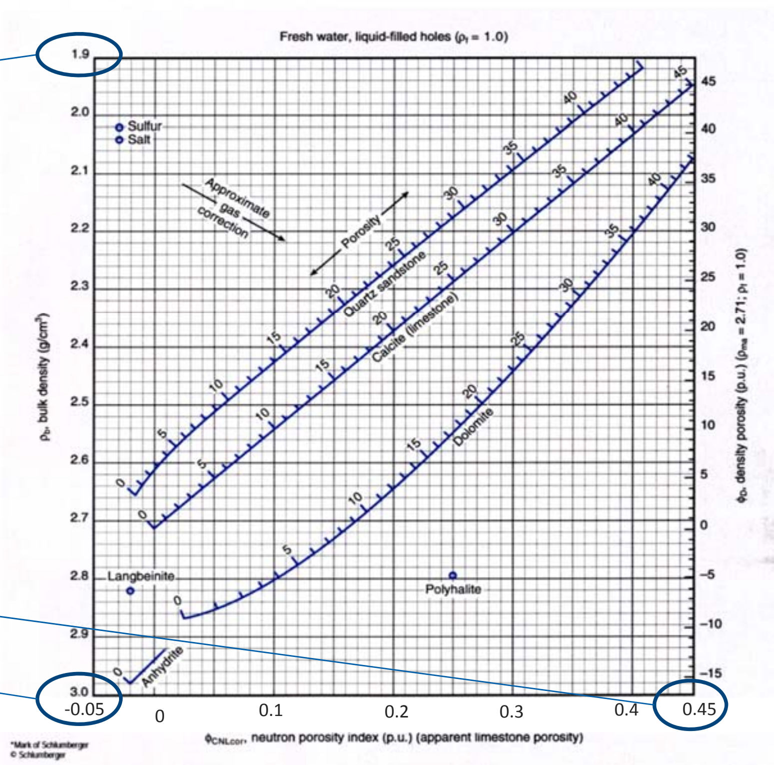
Generate NPHI-RHOB cross-plots



Note: Verify, NPHI unit is Porosity

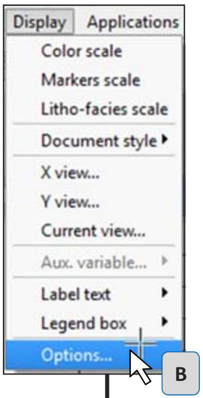
Porosity and Lithology Determination from Formation Density Log and CNL* Compensated Neutron Log
For CNL logs before 1986, or labeled NPHI

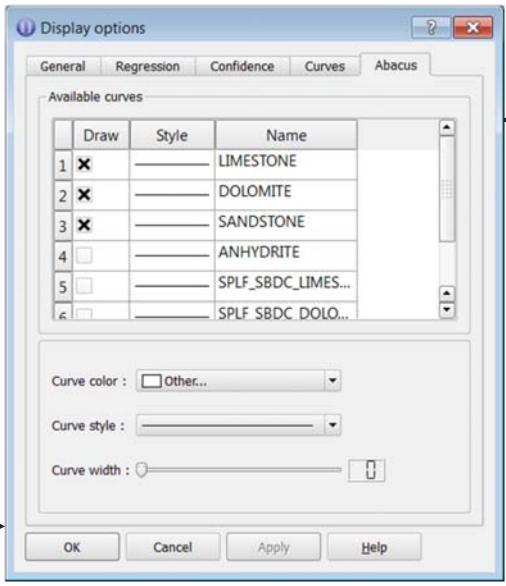
CP-1c

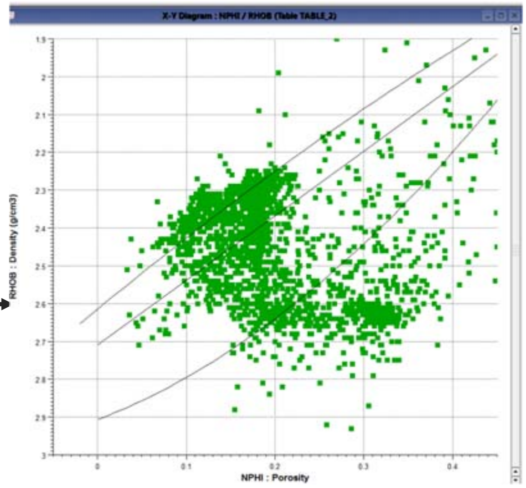


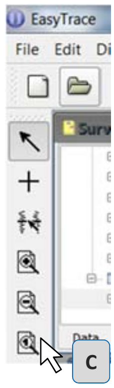
Display abacus

- Only if, before you create your table, you change the unit for NPHI from Anonymous to Porosity (See slide "to activate abacus")
- Select your NPHI/Rhob graph, "Display", "Options" (A), "Abacus" and select, Limestone, Dolomite and Sandstone (B)
- Click on the "Full view" icon to visualize the changes (C)

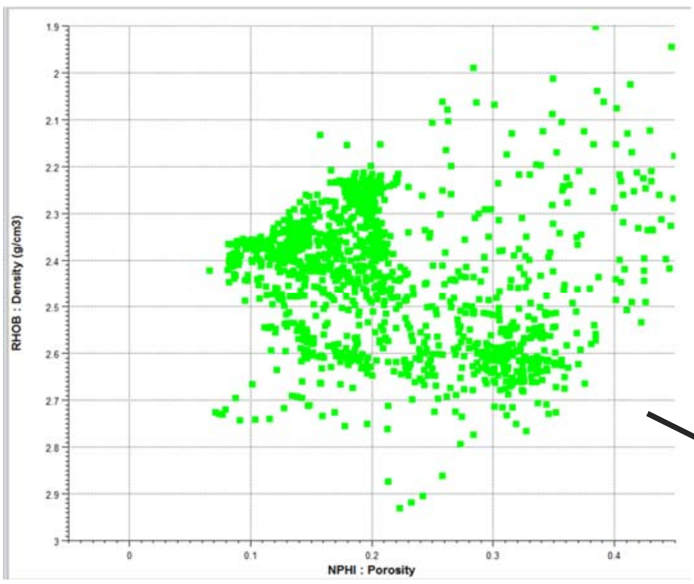


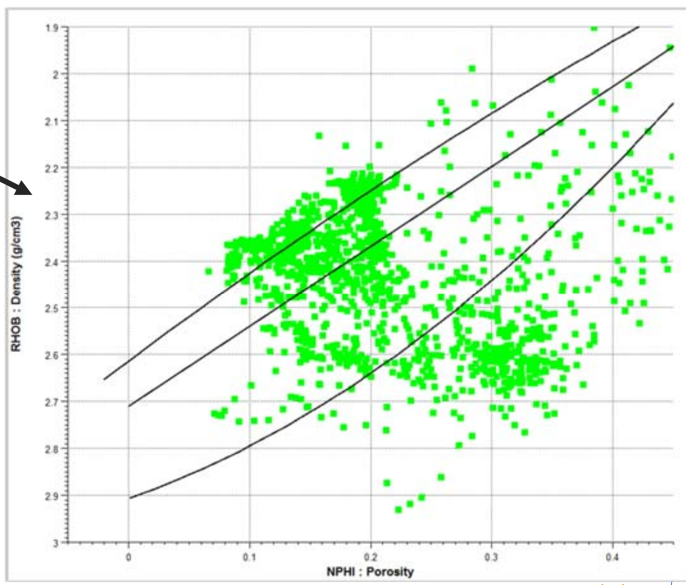




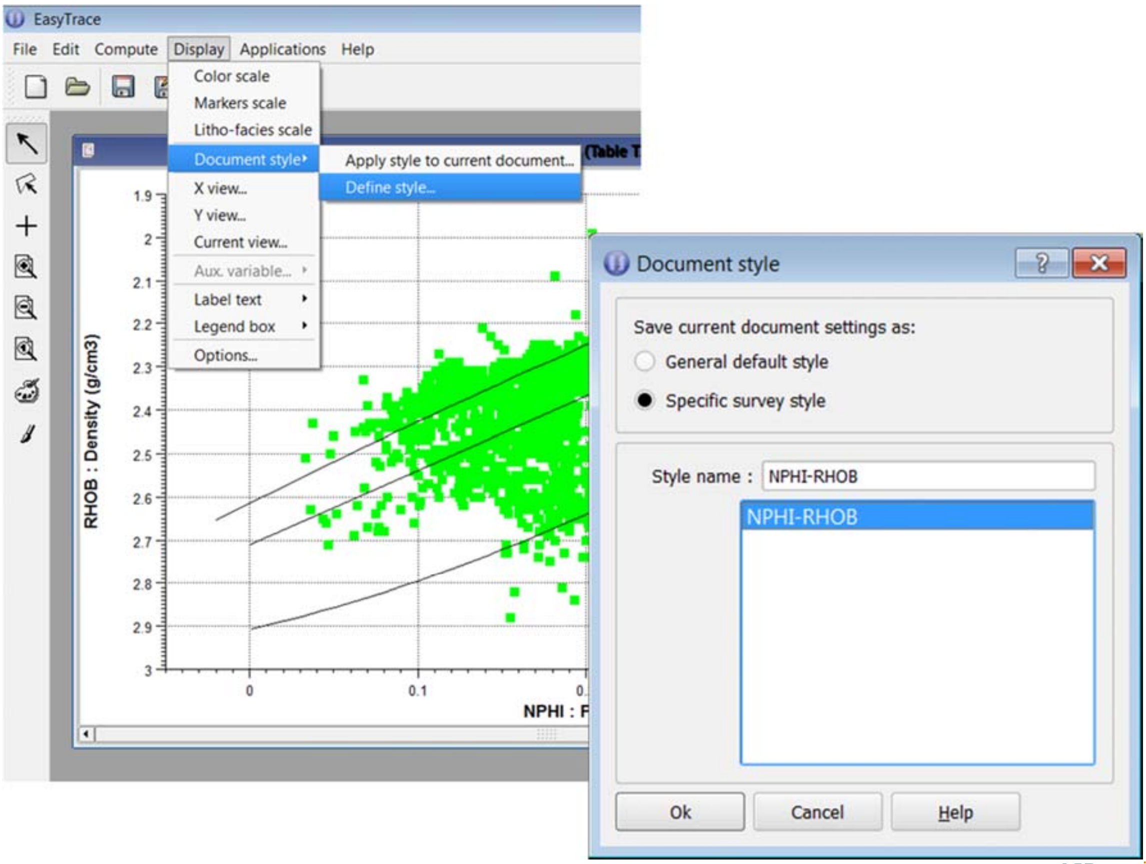


Results



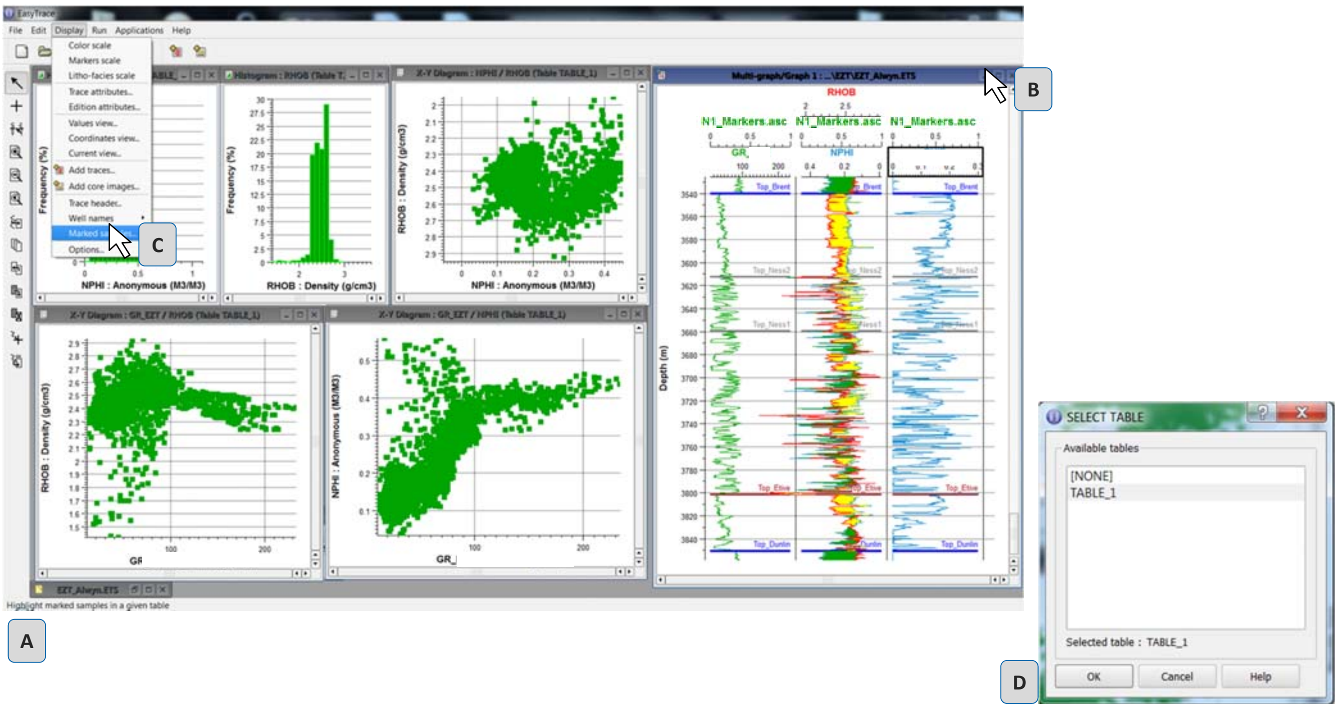


Save the display for Hands-on



Preliminary cross-plot analysis - Connect all plots - 1/2

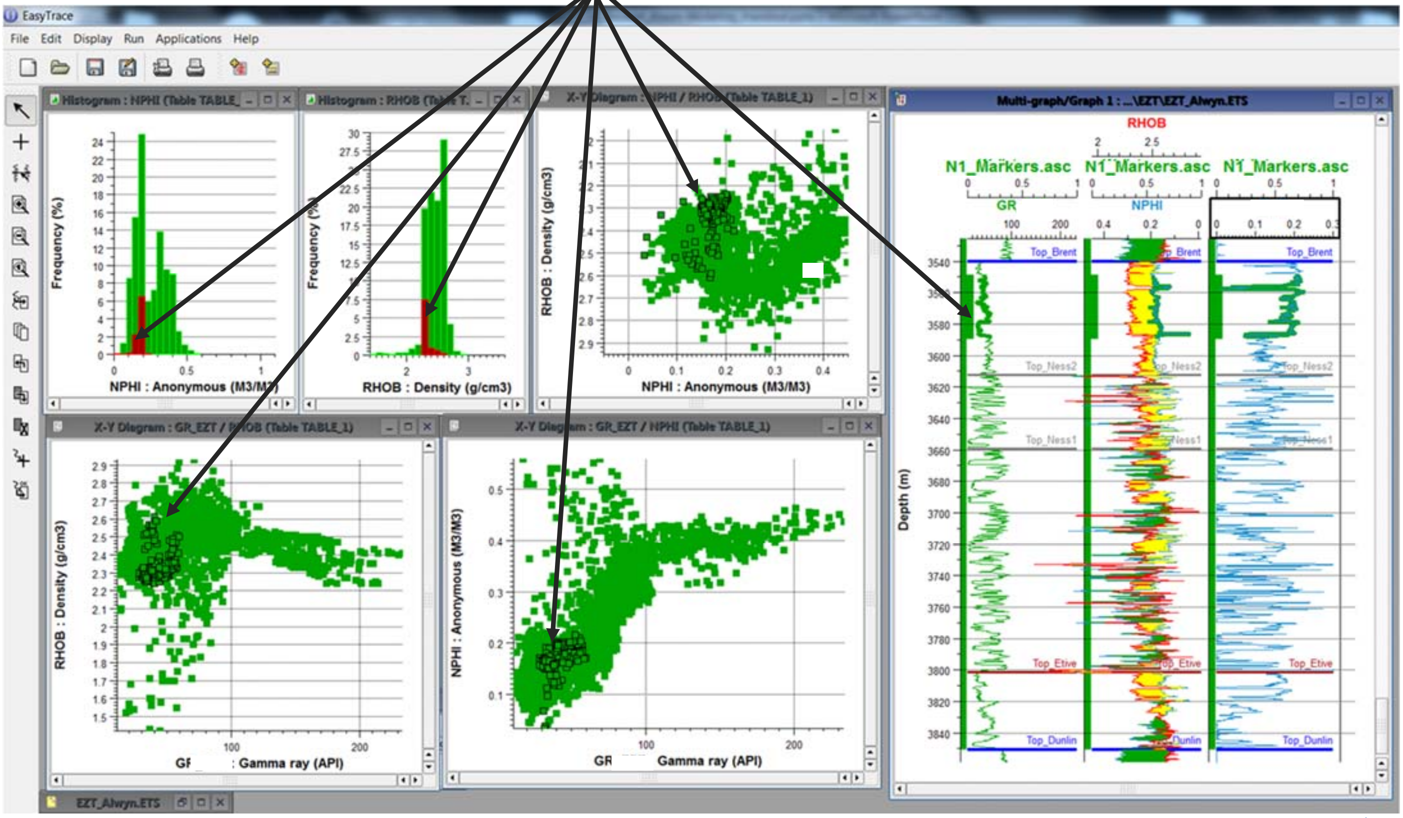
- Organize the plot as presented on (A)
- Select the Multi-graph window (log) (B)
- Display → Marked samples… (C)
- Select the Table



Preliminary cross-plot analysis - Connect all plots - 2/2

Dynamic selection: Full interactivity between all plots

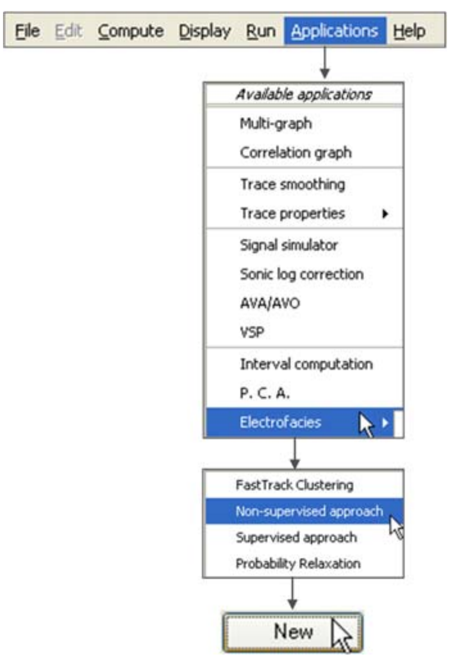
Results



Non-supervised approach

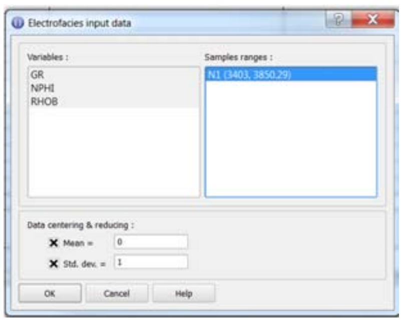
Non-supervised approach

1 - Create a new approach

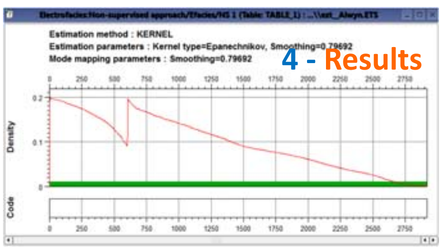


2 - Select the table

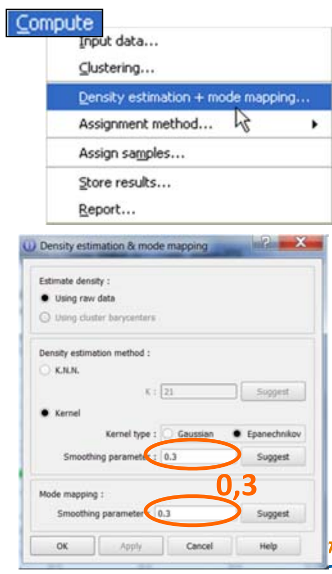
3 - Select the variable



4 - Results



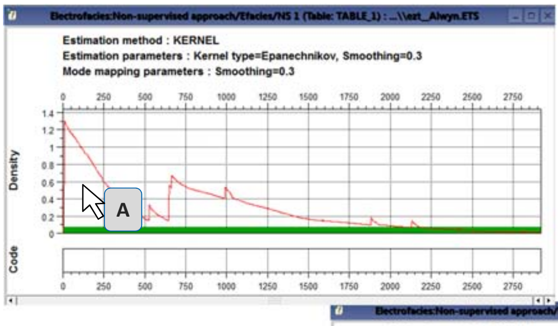
5 - Display results to adjust smoothing* parameters

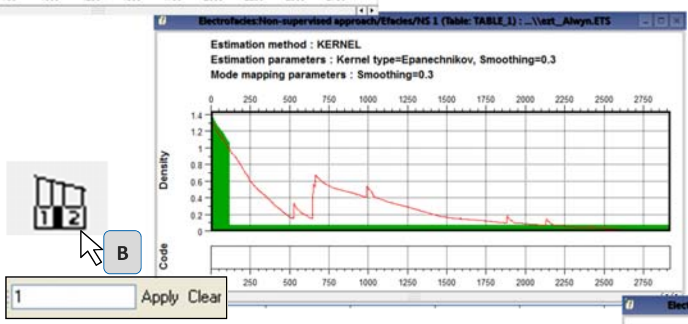


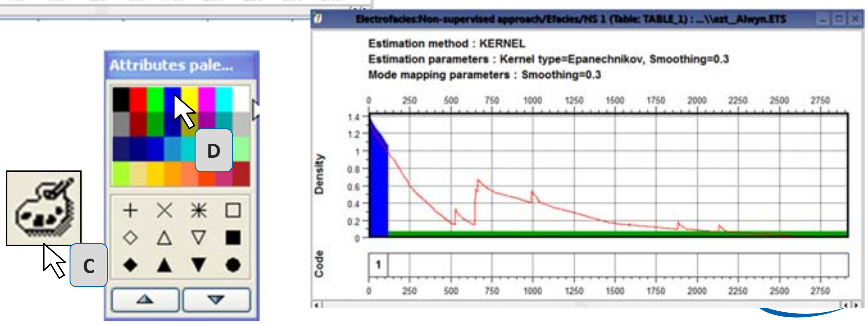
* Note: smoothing has a strong impact on the peak number and distribution →

Estimated Density Function - Peak sample selection

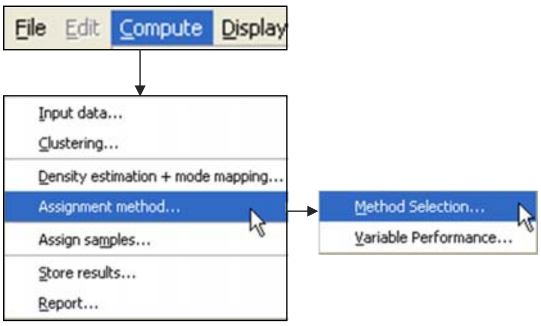
- **Select peaks on Estimated Density Function**
  - Select the first peak sample on Density graph (A). Click the selected interval on the right and move the arrow to the left
  - Click on the “Show/hide code assignment” icon (B) in the toolbar to assign the selected peak sample a number and validate with “Apply”
  - Repeat the operation for the other peaks identified on the EDF (A)
  - Select the numbered samples in the Code bar (below); call the palette (C) on the side toolbar and assign each peak a color (D)

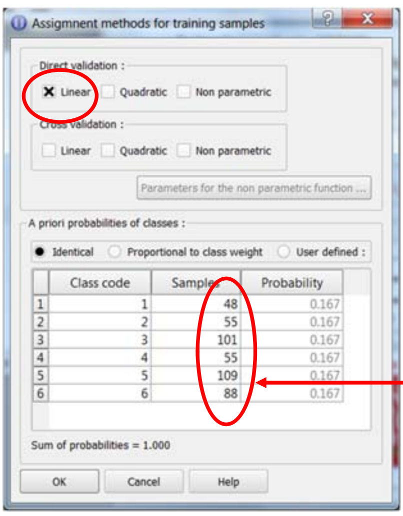


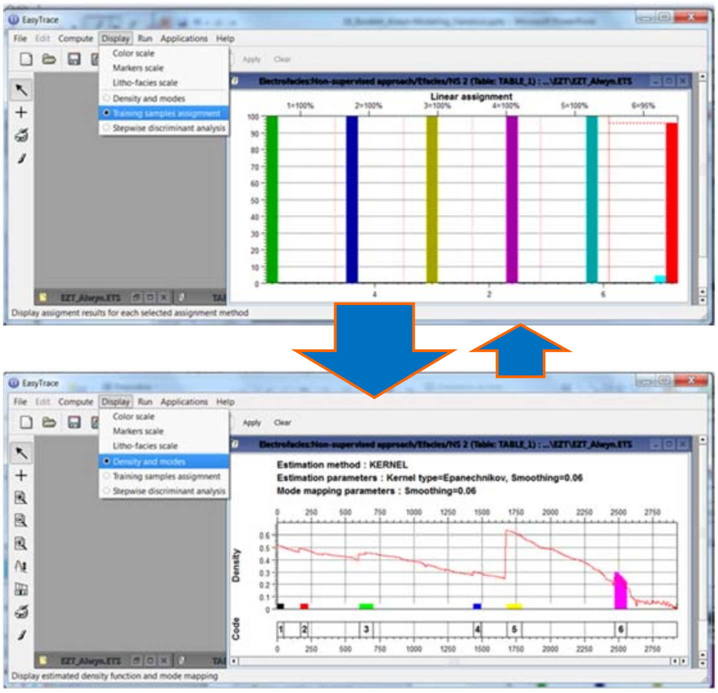




Estimated Density Function - Peak sample extension







- **Extend peak samples**
  - Select Linear method (for classes with limited number of points)
  - Quadratic method will increase percentage but will also force rules (more uncertainties)
  - Note that statistics are meaningless for logs with less than 15 samples

Histogram analysis

Description :

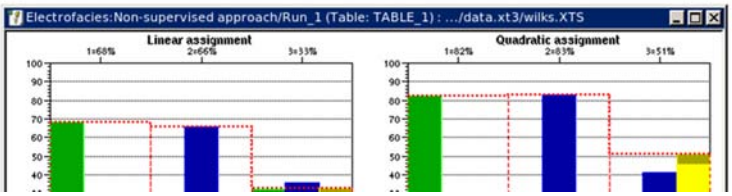
This document lets you view and edit a given *run* (i.e. instance) of the **Electrofacies** integrated application. The **Electrofacies** application is dedicated to the determination of the electrofacies with or without *a priori* information (supervised approach or non supervised approach).

When running with no *a priori* information (the non supervised approach), the document lets you view the estimated density function. On this image, you will have to delimit the various apparent *modes* (see the above figure). The purpose of this operation is to assign the same electrofacies code to series of samples that lie in the same high density region. The samples that receive an electrofacies code are then used as the training population to build the assignment function with.

Using this modes, or using an existing information (such as the lithology), it is then possible to compare the efficiency of various assignment functions, and then use one of these functions to assign an electrofacies code to other samples.

The scores obtained by each assignment functions are represented by histograms showing, for each electrofacies code, the percentage of samples assigned to a different class (see figure below).

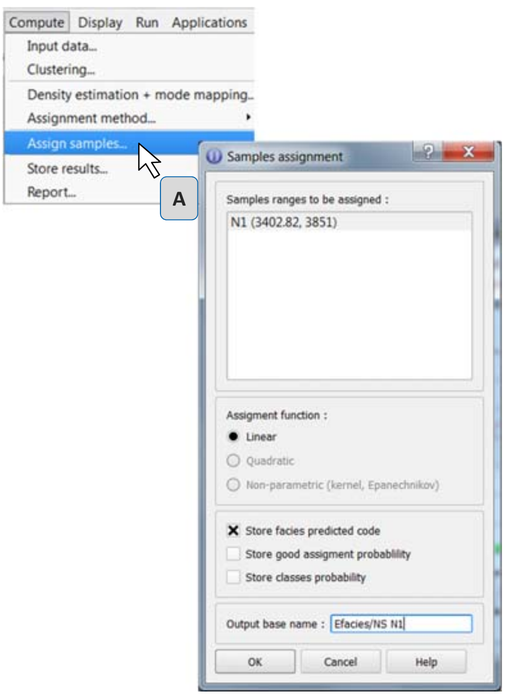
A specific procedure, called the *cross-validation*, can be used to obtain a more robust estimation of the function efficiency. When using this procedure, each sample is removed from the population before searching the class it will be assigned to.

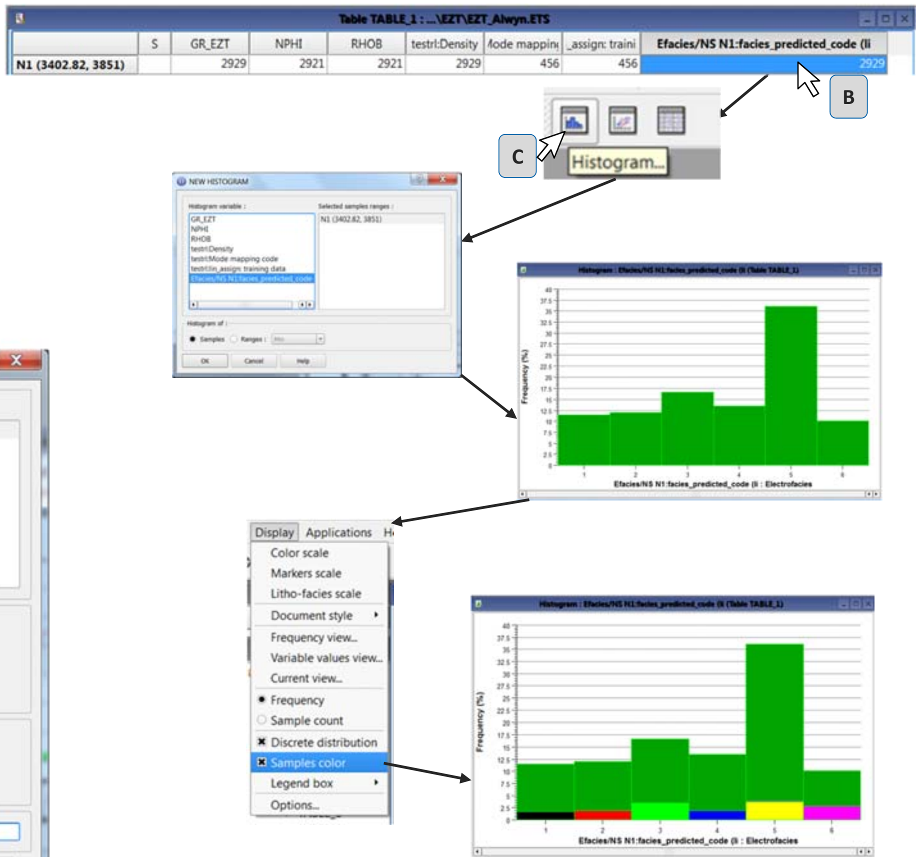


Indicate the level of assignment directly linked with the shape of the histogram

Assign electrofacies – 1/3

Assign samples
- Compute → Assign samples (A)
- Select the table where assignment results are now available
- Generate the histogram and use
- Display → samples color

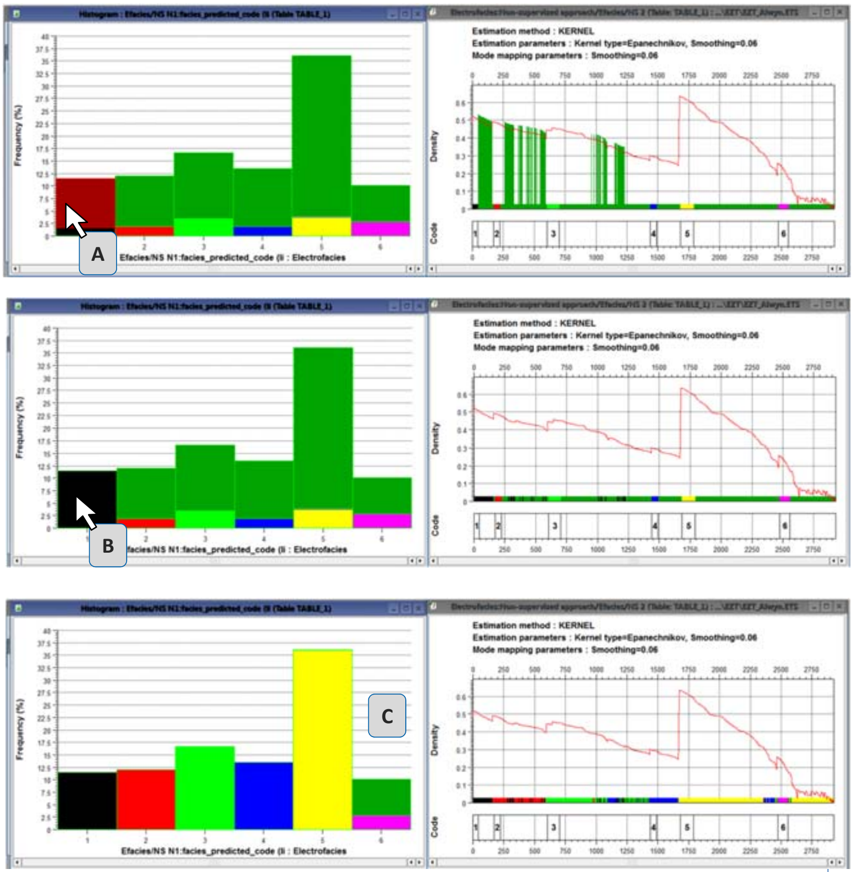




Assign electrofacies – 2/2

Assign samples colors

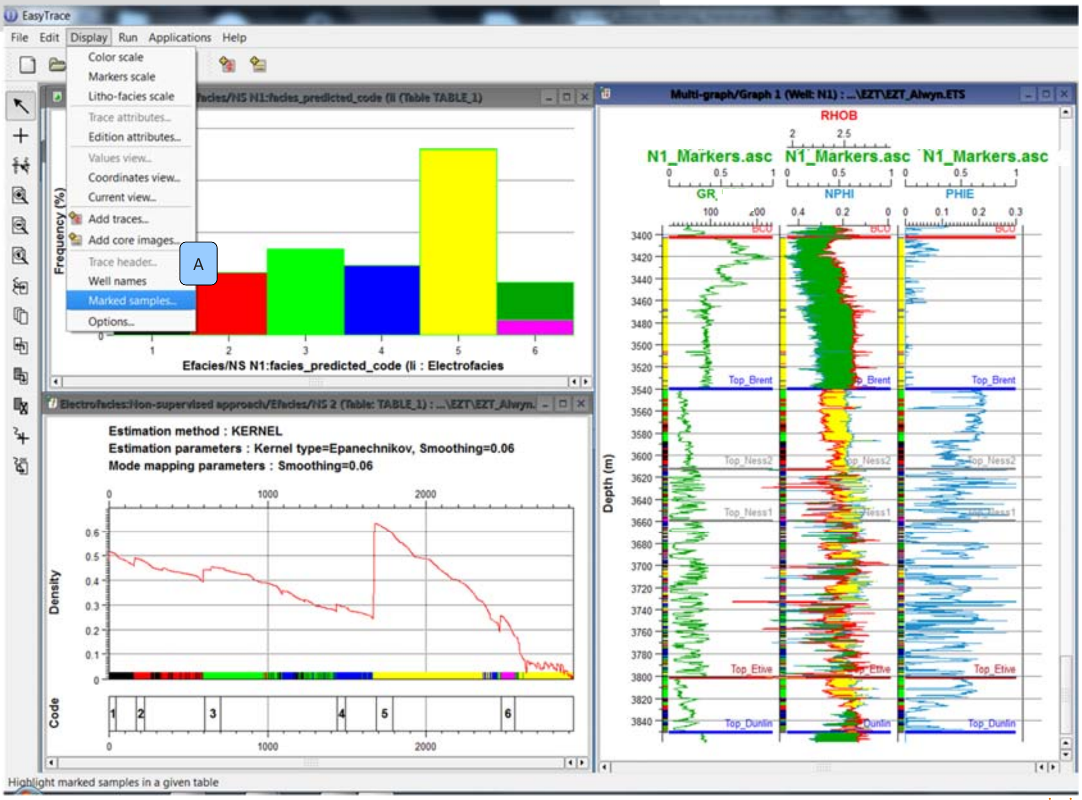
- Select the non-assigned samples (A) on the histogram to assign the peak color
- See the result on (B)
- Repeat the operation for other histogram bar (C)
- Select histogram → Display → Sample color



Connect all plots interactively

- Select Multi_Graph and Display → Select "Marked samples" to visualize the results (A)

Fully interactive analysis on 3 connected plots



Real case hands-on

Objectives

Part 3B

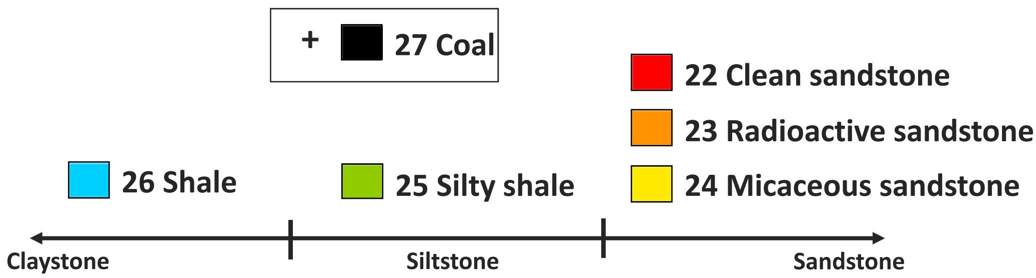
Hands-on session: Objectives and steps

1. **Load data set using all the available wells (“N” and “A”)**
2. **Build a multi-trace (composite) plot for the reference well N2 with the following log suite:**
   - GR, RHOB, NPHI
3. **Create a cross-plot and connect all the windows for preliminary cross-plot analysis**
4. **Perform a “non-supervised” clustering with the following logs on the reference well N2 (= master well)**
   - GR + NPHI + RHOB
5. **Perform a supervised analysis via core-to-log correlation on the reference well (N2)**
   - Use core description from reference well loading “N2_Lithofacies.las”
   - Assign the result to all the wells
6. **Compare and comment the results from both approaches**
   - Spot the differences
   - Identify the best ones
7. **Select well N2 and import K_CORE and PHI_CORE from file N2_CCAL_Shifted.las**
8. **Build a multi-graph (composite) plot for the reference well N2 with the following log suite:**
9. **In multi-graph composite, add K_CORE and PHI_CORE**
10. **Perform a petrophysical analysis for each facies**

Supervised approach

Core description and facies identification

- **Core on N2** (reference well)**:**
  - 266m cored (110m with images)
- **6 facies identified:**
  - 3 sandy facies with **high** reservoir potential
  - 1 silty/shaly facies with **low** reservoir potential
  - 2 other facies (shale and coal) with no reservoir potential
  - Lithofacies numbers range from 22 to 29



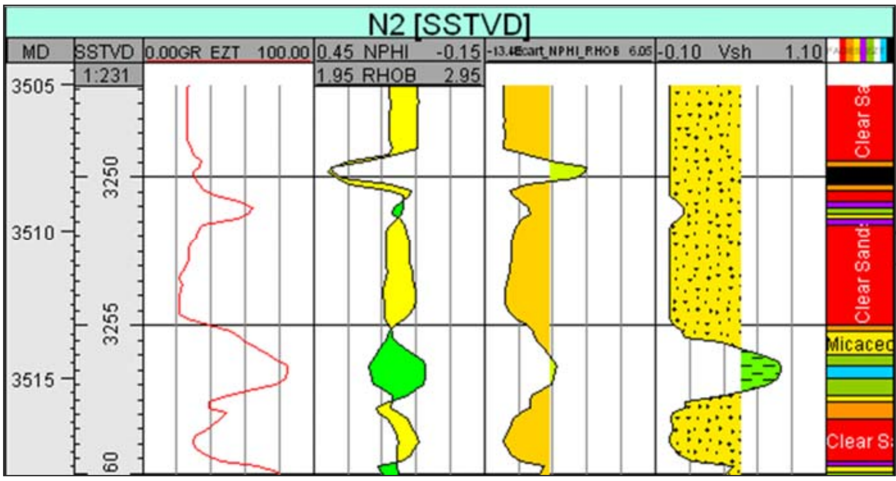
File created in Excel After core description

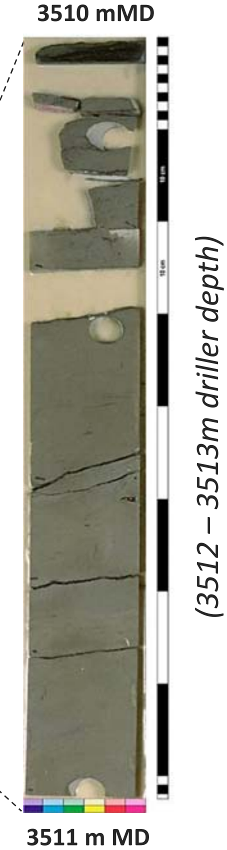
DEPTH	LITHOFACIES
3430.200	26
3430.400	26
3430.600	26
3430.800	26
3431.000	26
3431.200	26
3431.400	26
3431.600	26
3431.800	26
3432.000	26
3432.200	26
3432.400	26
3432.600	26
3432.800	26
3433.000	26
3433.200	26
3433.400	26
3433.600	26
3433.800	26
3434.000	26
3434.200	26
3434.400	26
3434.600	26
3434.800	26
3435.000	26
3435.200	26
3435.400	26
3435.600	26
3435.800	26
3436.000	26
3443.000	23
3444.000	23
3458.200	23
3458.400	23
3458.600	23

22: Clean sandstone

- Single facies present in all BRENT zones
- Low distribution in Tarbert (8%)
- Main facies in Ness 2 (≈ 50%) and Ness 1 (≈ 30%)

→ **HIGH RESERVOIR QUALITY**

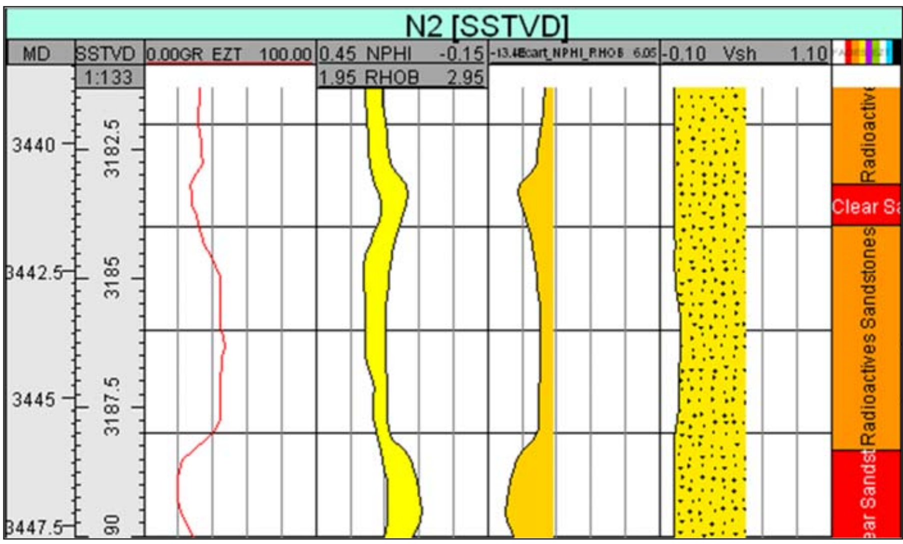


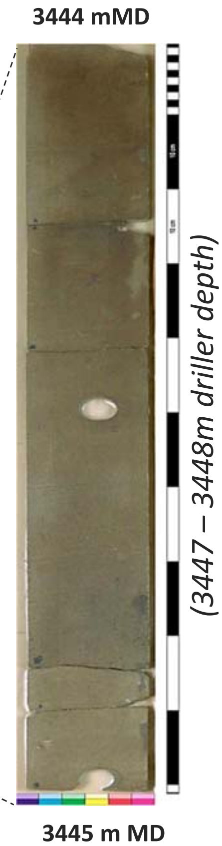


23: Radioactive sandstone

- Main facies in Tarbert (≈ 55%)
- Very low distribution in Ness (3% in Ness 2 and 8% in Ness 1)
- A few meters in the upper part of Etive

→ **HIGH RESERVOIR QUALITY**

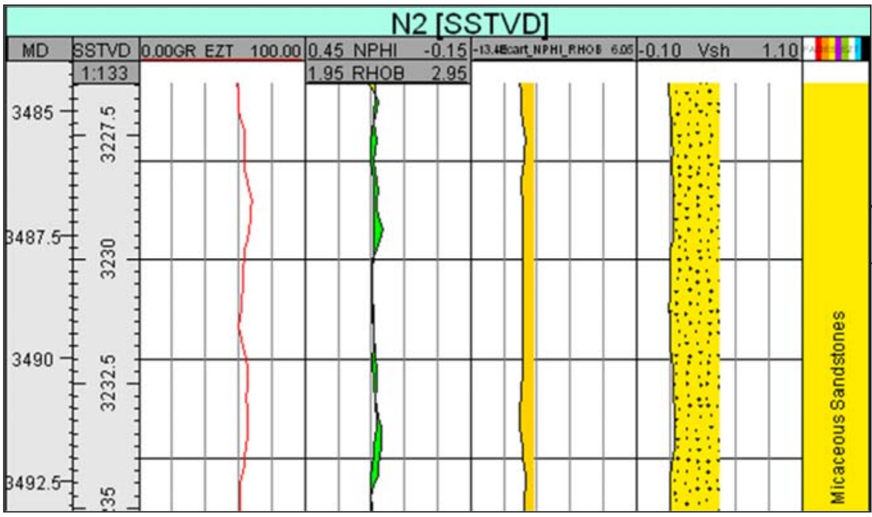




24: Micaceous sandstone

- Second main facies in Tarbert (≈ 30%)
- Second main facies in Ness 2 (≈ 15%); less in Ness 1 (≈ 10%)
- Not observed in Etive

→ LOW RESERVOIR QUALITY



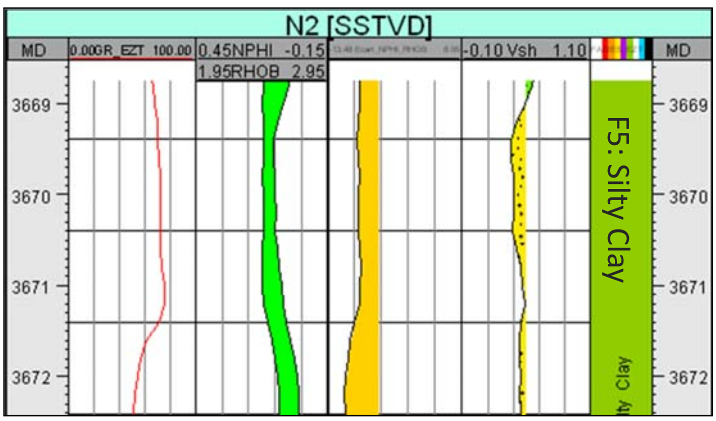
3487 mMD

3488 m MD

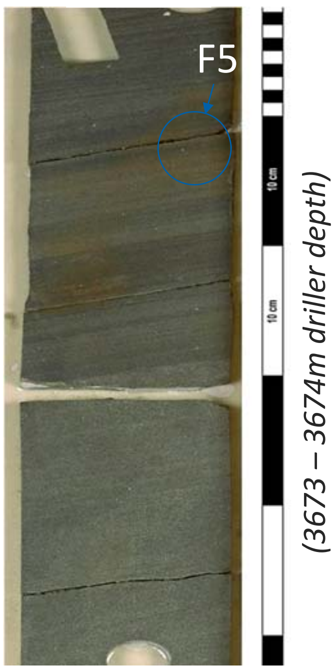
25: Silty shale

- Secondary facies only observed in Ness
- F5 and F6 represent 15% of Ness 2 and 20% of Ness 1
- High occurrence of F6 in Etive (66%)

→ NOT RESERVOIR



3670 mMD

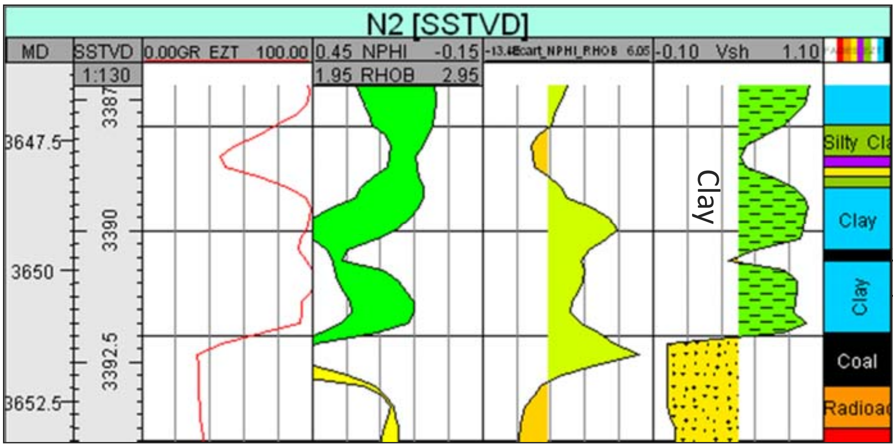


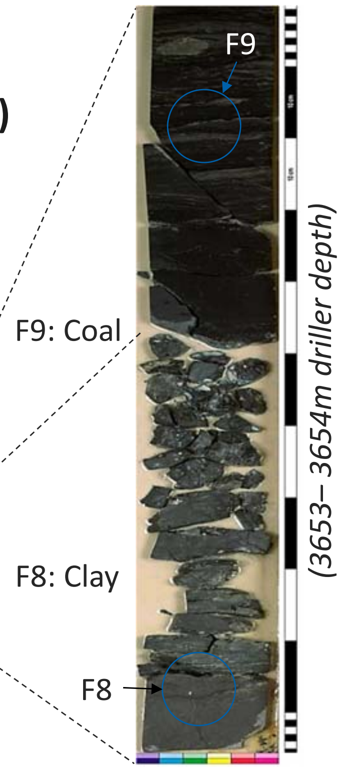
3670.5 m MD

26: Shale - 27: Coal

- Second main facies in Tarbert (≈ 30%)
- Second main facies in Ness 2 (≈ 15%); less in Ness 1 (≈ 10%)
- Not observed in Etive

→ NOT RESERVOIR

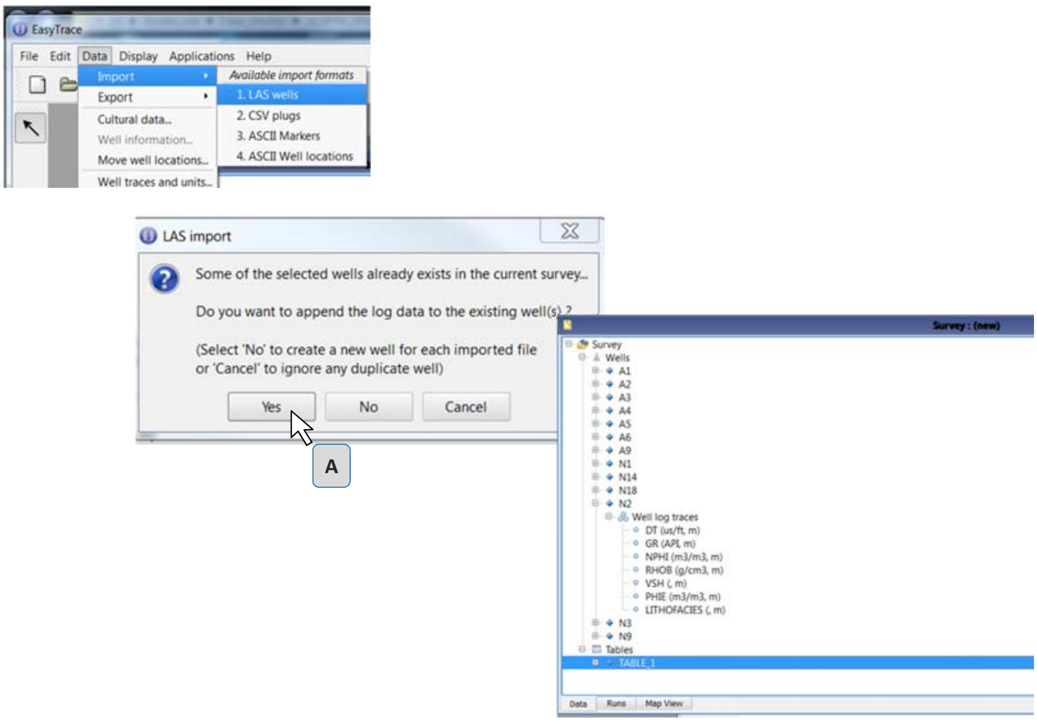




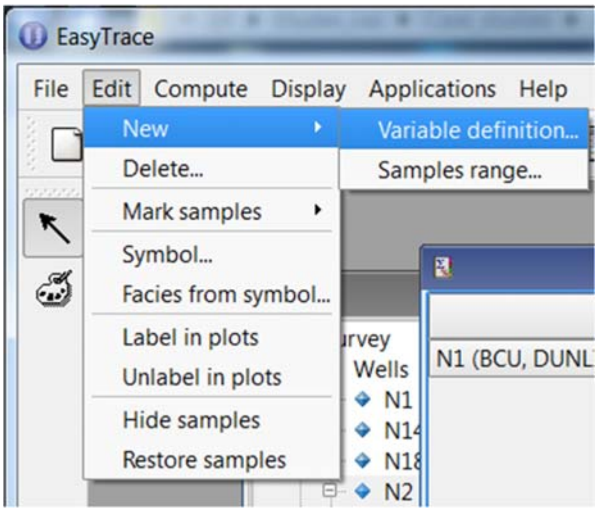
Supervised approach: load lithofacies

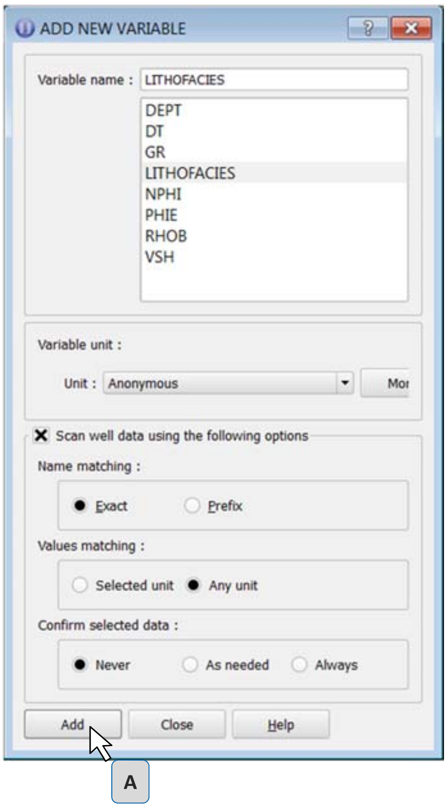
Load lithofacies

- Data → Import and select N2_Lithofacies.las and OK (A)

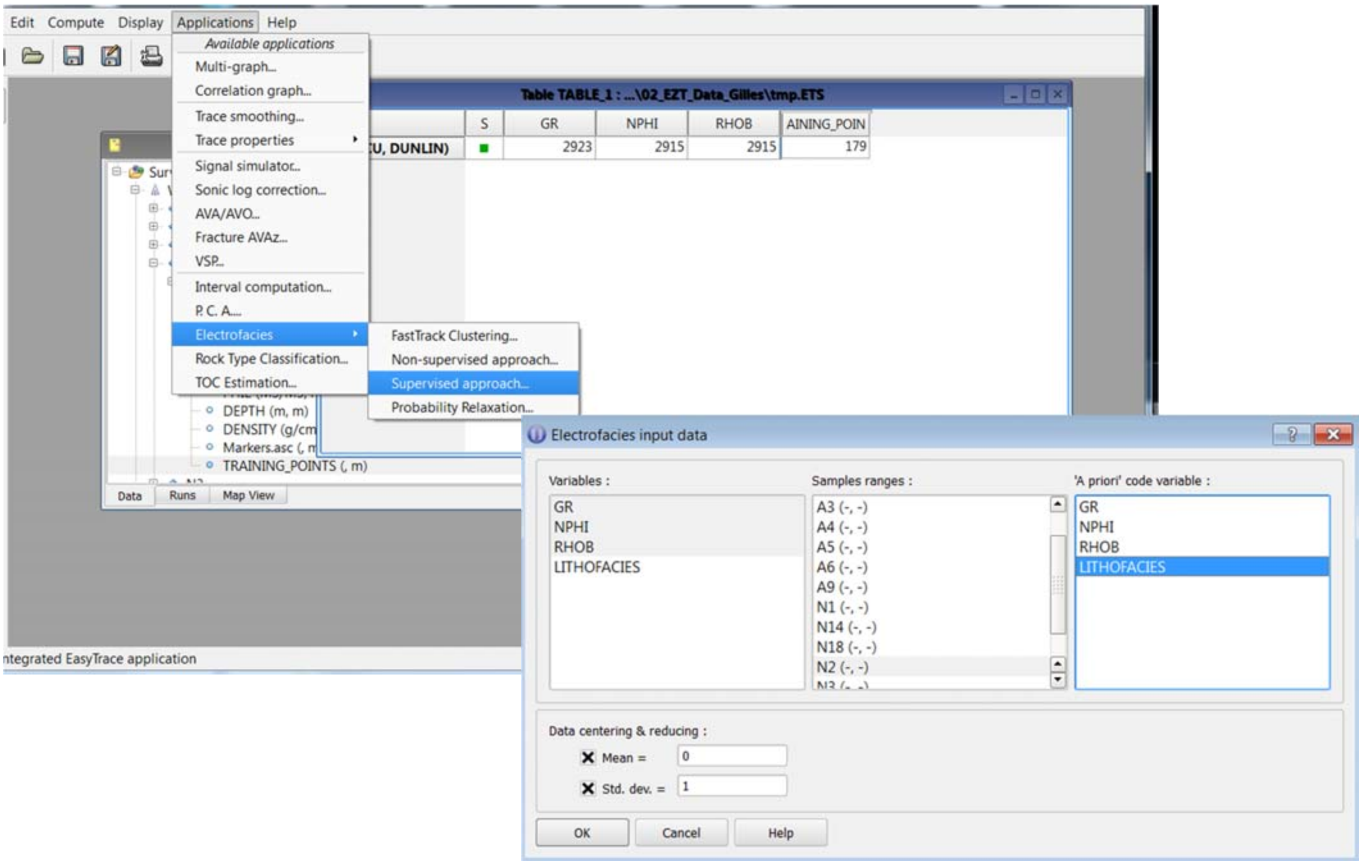


Add lithofacies to the table

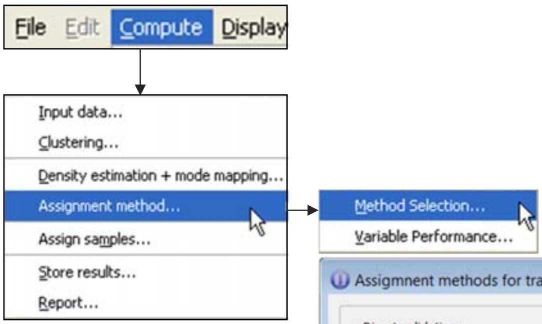


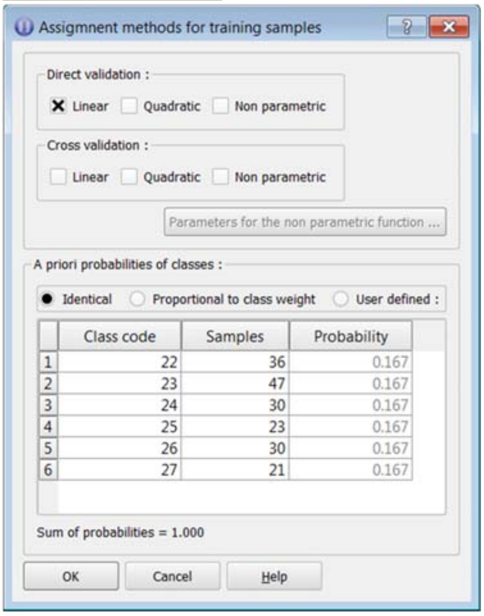


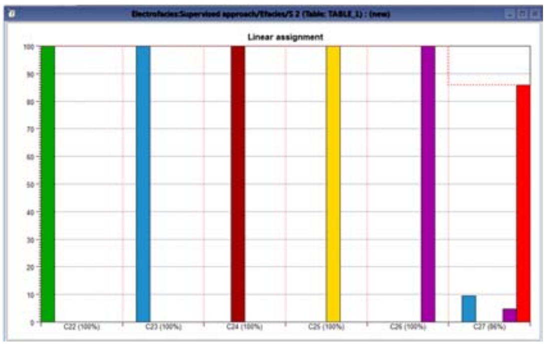
Supervised approach



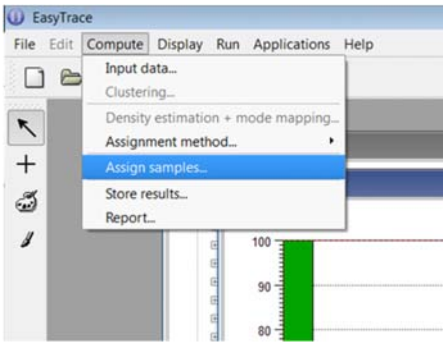
Assignment method selection



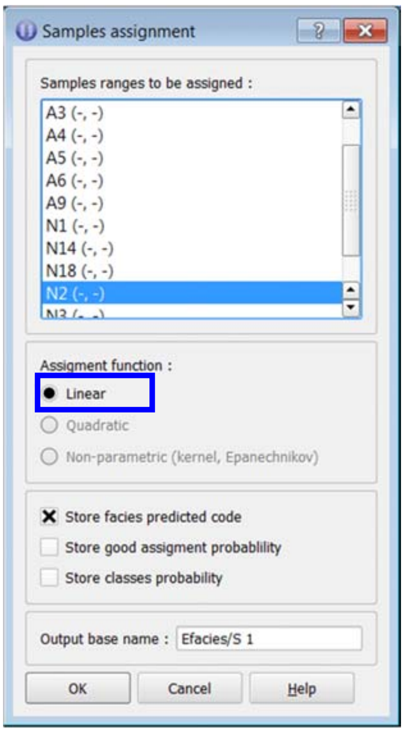




Assignments

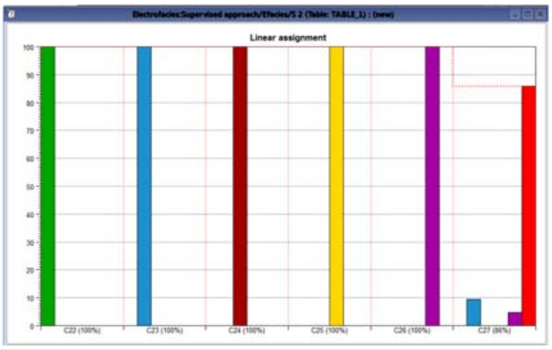


Datasets with a limited number of points
→ Use **linear method**



⚠ Only in well N2 first

Results – Assignment report



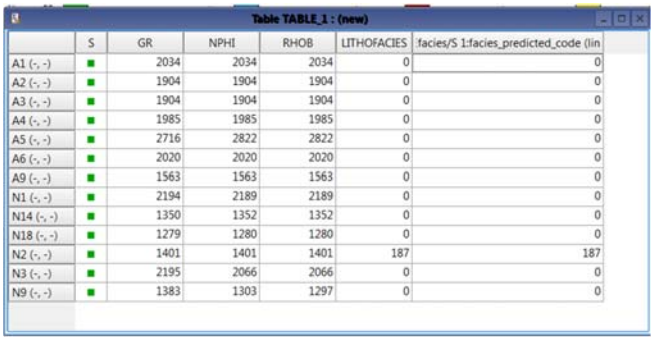
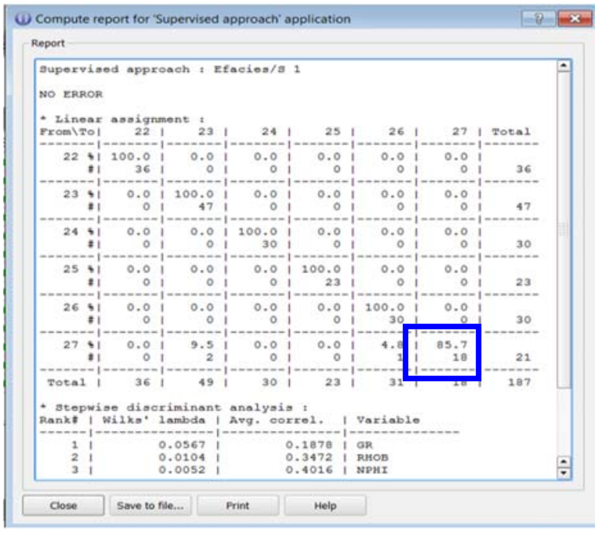


Table TABLE_1 : (new)

	S	GR	NPHI	RHOB	LITHOFACIES	facies/S 1:facies_predicted_code (lin
A1 (-, -)	■	2034	2034	2034	0	0
A2 (-, -)	■	1904	1904	1904	0	0
A3 (-, -)	■	1904	1904	1904	0	0
A4 (-, -)	■	1985	1985	1985	0	0
A5 (-, -)	■	2716	2822	2822	0	0
A6 (-, -)	■	2020	2020	2020	0	0
A9 (-, -)	■	1563	1563	1563	0	0
N1 (-, -)	■	2194	2189	2189	0	0
N14 (-, -)	■	1350	1352	1352	0	0
N18 (-, -)	■	1279	1280	1280	0	0
N2 (-, -)	■	1401	1401	1401	187	187
N3 (-, -)	■	2195	2066	2066	0	0
N9 (-, -)	■	1383	1303	1297	0	0



Compute report for 'Supervised approach' application

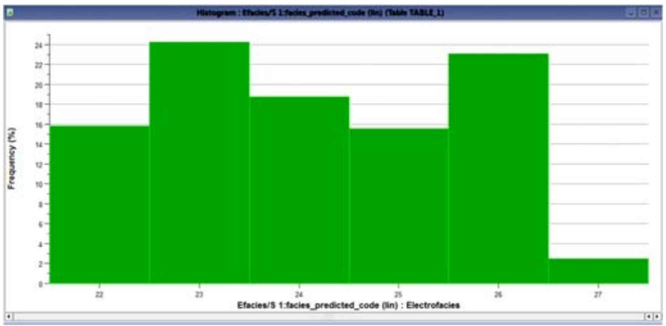
Report

```
Supervised approach : Efacies/S 1

NO ERROR

* Linear assignment :
From\To|    22 |    23 |    24 |    25 |    26 |    27 | Total
-------|-------|-------|-------|-------|-------|-------|-------
  22 %| 100.0 |   0.0 |   0.0 |   0.0 |   0.0 |   0.0 |
     #|    36 |     0 |     0 |     0 |     0 |     0 |    36
-------|-------|-------|-------|-------|-------|-------|-------
  23 %|   0.0 | 100.0 |   0.0 |   0.0 |   0.0 |   0.0 |
     #|     0 |    47 |     0 |     0 |     0 |     0 |    47
-------|-------|-------|-------|-------|-------|-------|-------
  24 %|   0.0 |   0.0 | 100.0 |   0.0 |   0.0 |   0.0 |
     #|     0 |     0 |    30 |     0 |     0 |     0 |    30
-------|-------|-------|-------|-------|-------|-------|-------
  25 %|   0.0 |   0.0 |   0.0 | 100.0 |   0.0 |   0.0 |
     #|     0 |     0 |     0 |    23 |     0 |     0 |    23
-------|-------|-------|-------|-------|-------|-------|-------
  26 %|   0.0 |   0.0 |   0.0 |   0.0 | 100.0 |   0.0 |
     #|     0 |     0 |     0 |     0 |    30 |     0 |    30
-------|-------|-------|-------|-------|-------|-------|-------
  27 %|   0.0 |   9.5 |   0.0 |   0.0 |   4.8 |  85.7 |
     #|     0 |     2 |     0 |     0 |     1 |    18 |    21
-------|-------|-------|-------|-------|-------|-------|-------
 Total |    36 |    49 |    30 |    23 |    31 |    18 |   187

* Stepwise discriminant analysis :
Rank# | Wilks' lambda | Avg. correl.  | Variable
------|---------------|---------------|------------
    1 |        0.0567 |        0.1878 | GR
    2 |        0.0104 |        0.3472 | RHOB
    3 |        0.0052 |        0.4016 | NPHI
```

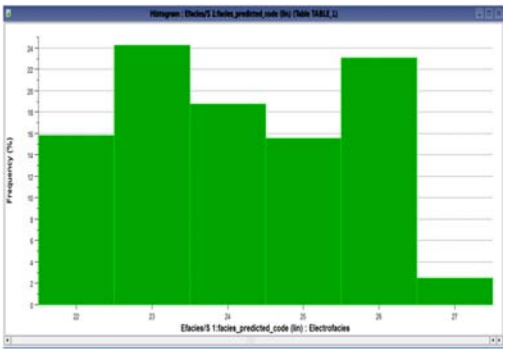
Close | Save to file... | Print | Help

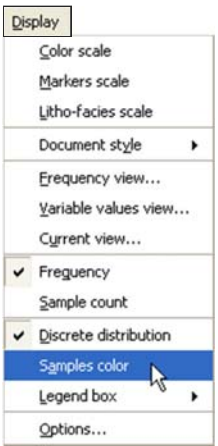
Datasets with limited number of points → Use **linear method**

Generate a histogram and check if points assignation is consistent with respect to the geological descriptions



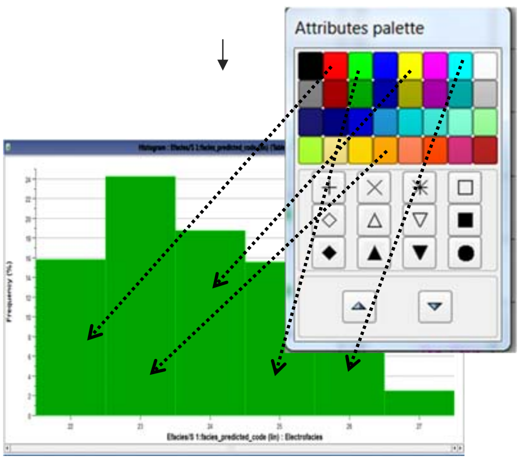
Display results in color

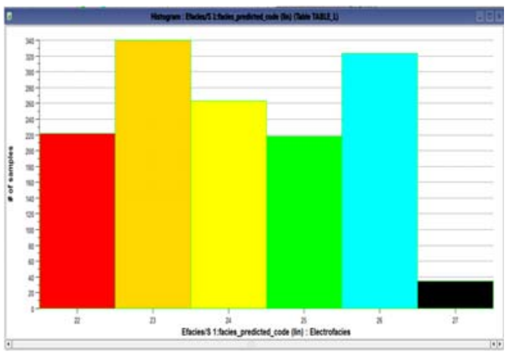




Propagate the supervised approach results to non-cored wells

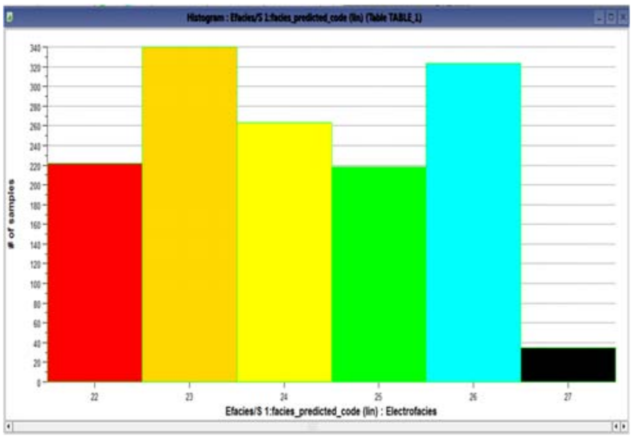
Compute → Assign samples → Select all wells



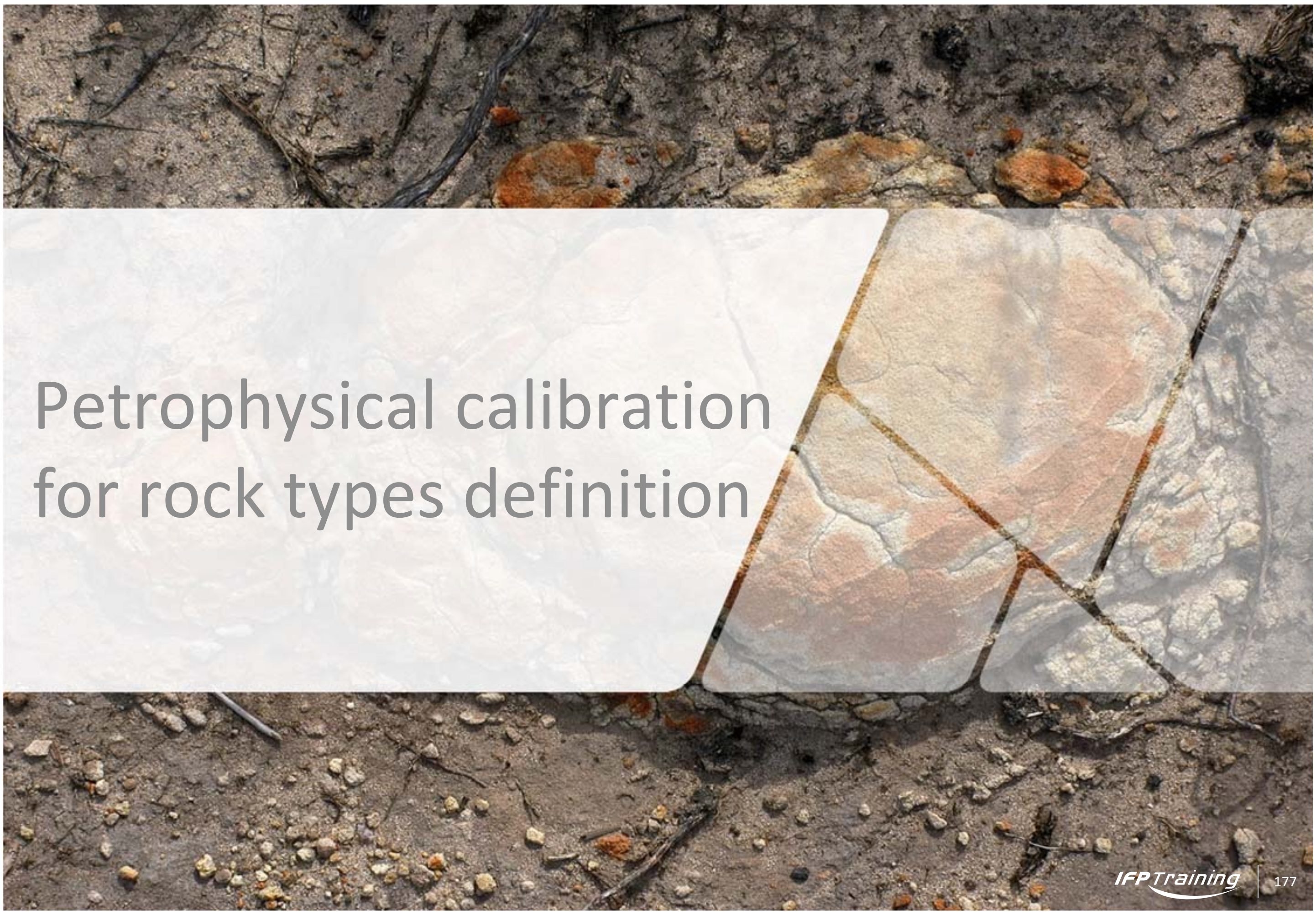


Supervised approach summary: “Lithofacies”

- Clean sandstone (EF-22)
- Radioactive sandstone (EF-23)
- Micaceous sandstone (EF-24)
- Silty shale (EF-25)
- Shale (EF-26)
- Coal (EF-27)



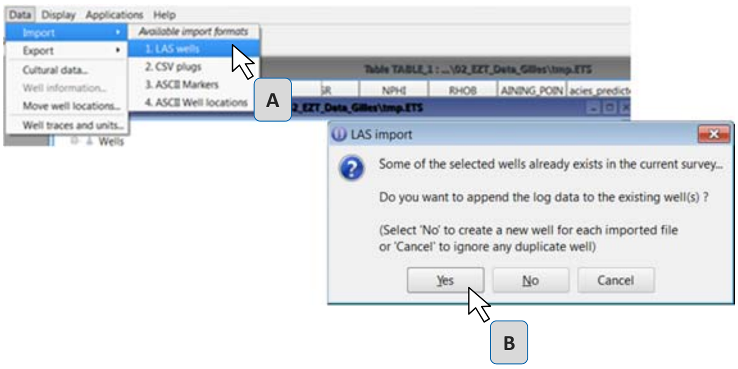
→ *Start the Petrophysical calibration HOP with Easy Trace*

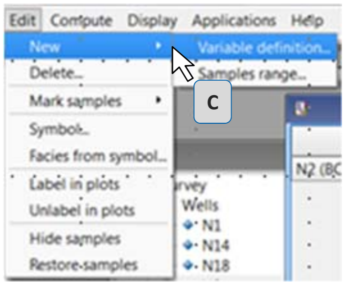


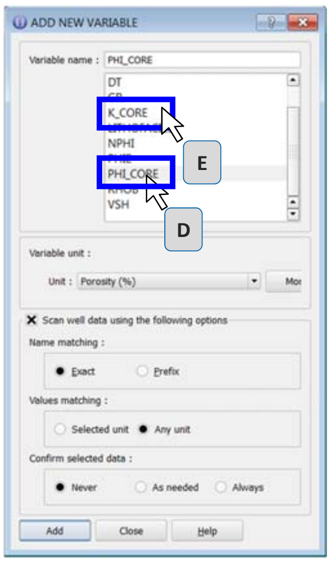
Petrophysical calibration for rock types definition

Porosity / Permeability form core

- Load Petrophysical core data for well N2 “N2_CCAL_Shifted” (A) and (B)
- Select your table and Integrate PHI_CORE (D) and K_CORE € in your table

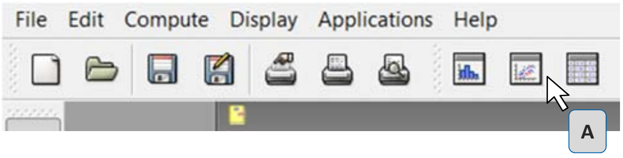


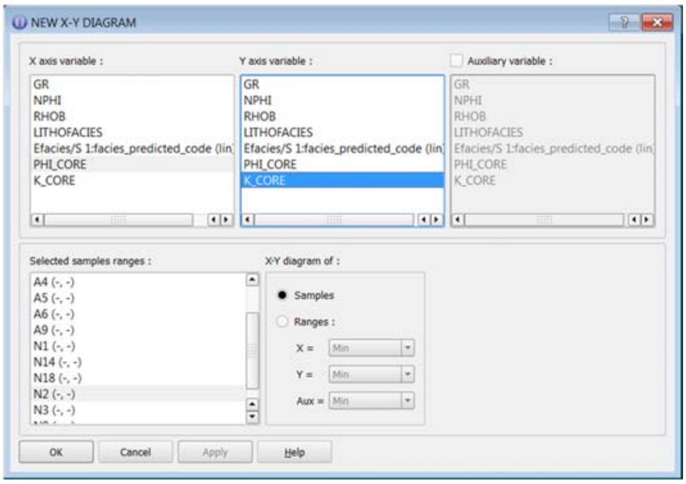


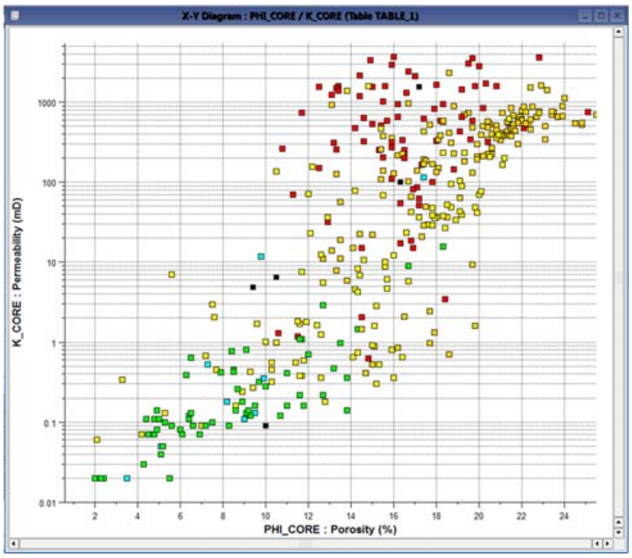


Porosity / Permeability diagram from core

- Select the table and click on the XY diagram icon (A)
- Display the Y view with logarithmic scale

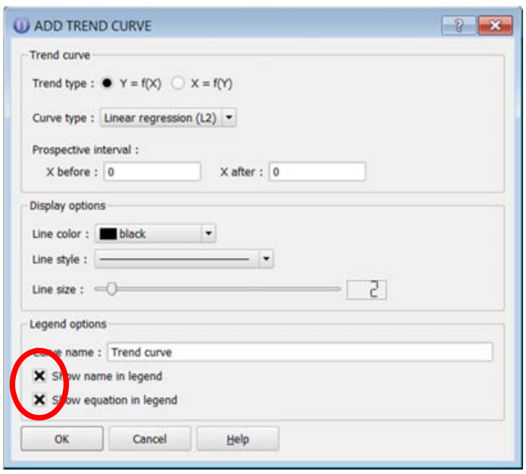


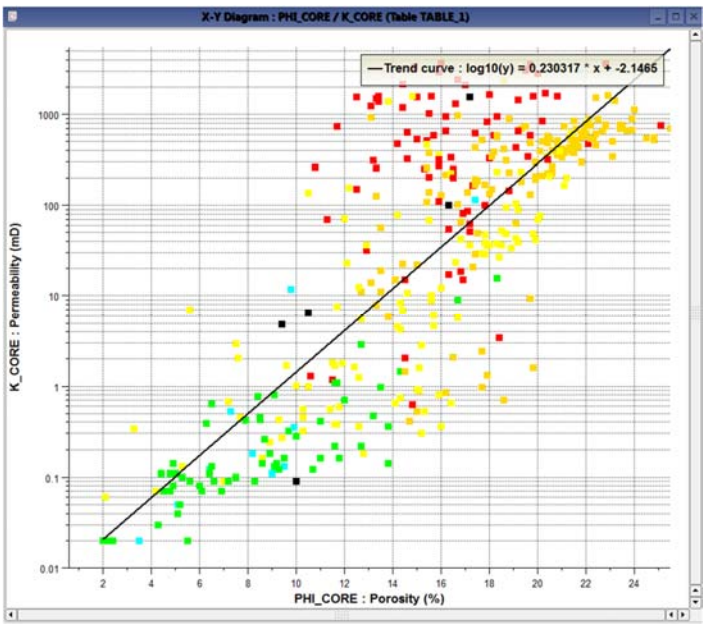




Display statistical distribution (Regression line)

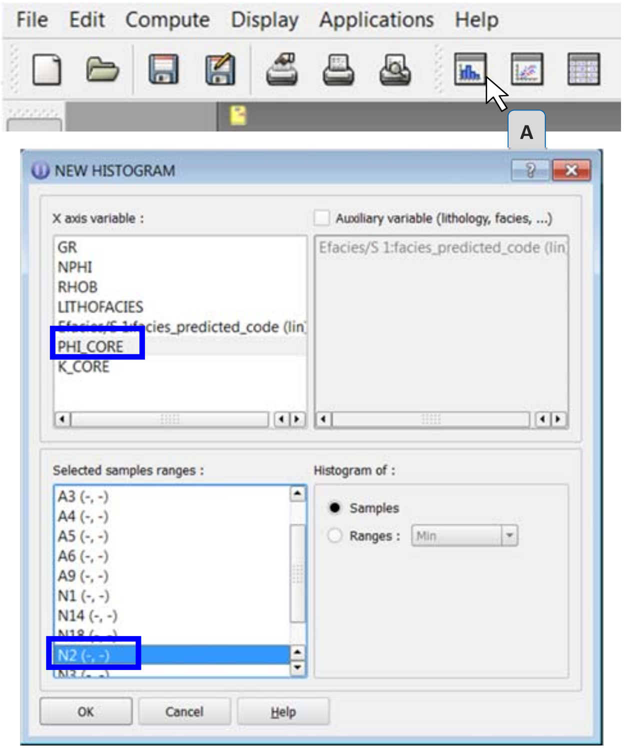
- Select the XY diagram icon
- Compute – Add trend curve

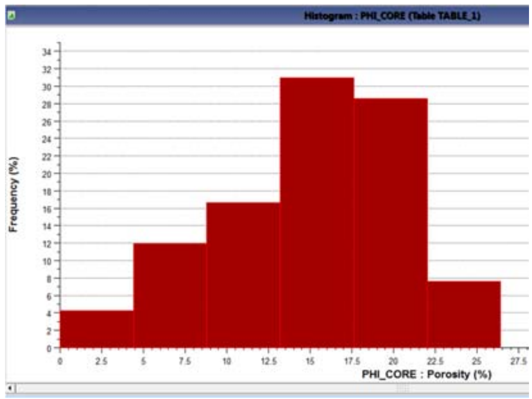




Histogram porosity from core

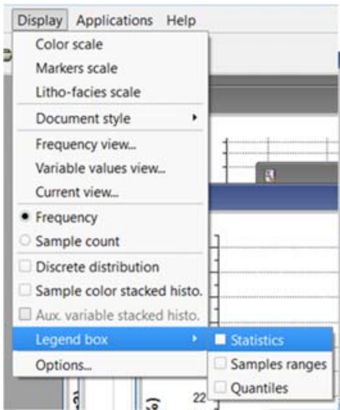
- Select the table and click on the histogram diagram icon (A)
- Select PHI_CORE and well N2

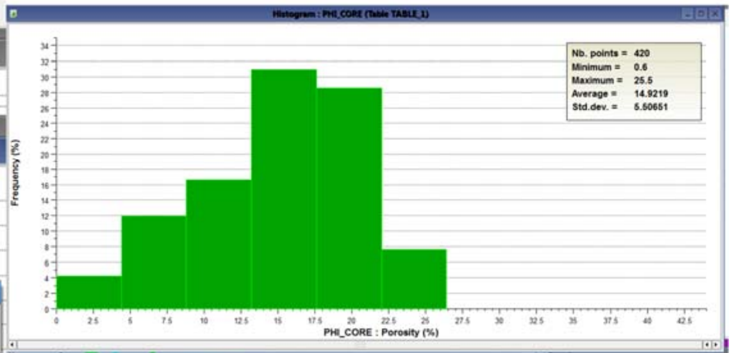


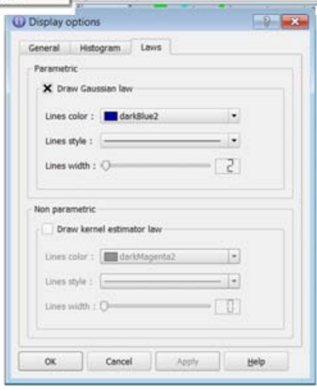


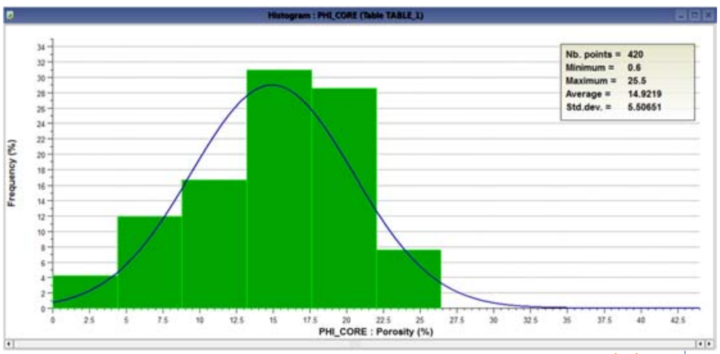
Display statistics and Gaussian law

- Select the table an click on the histogram diagram icon (A)
- Select the legend box and select “Gaussian law”

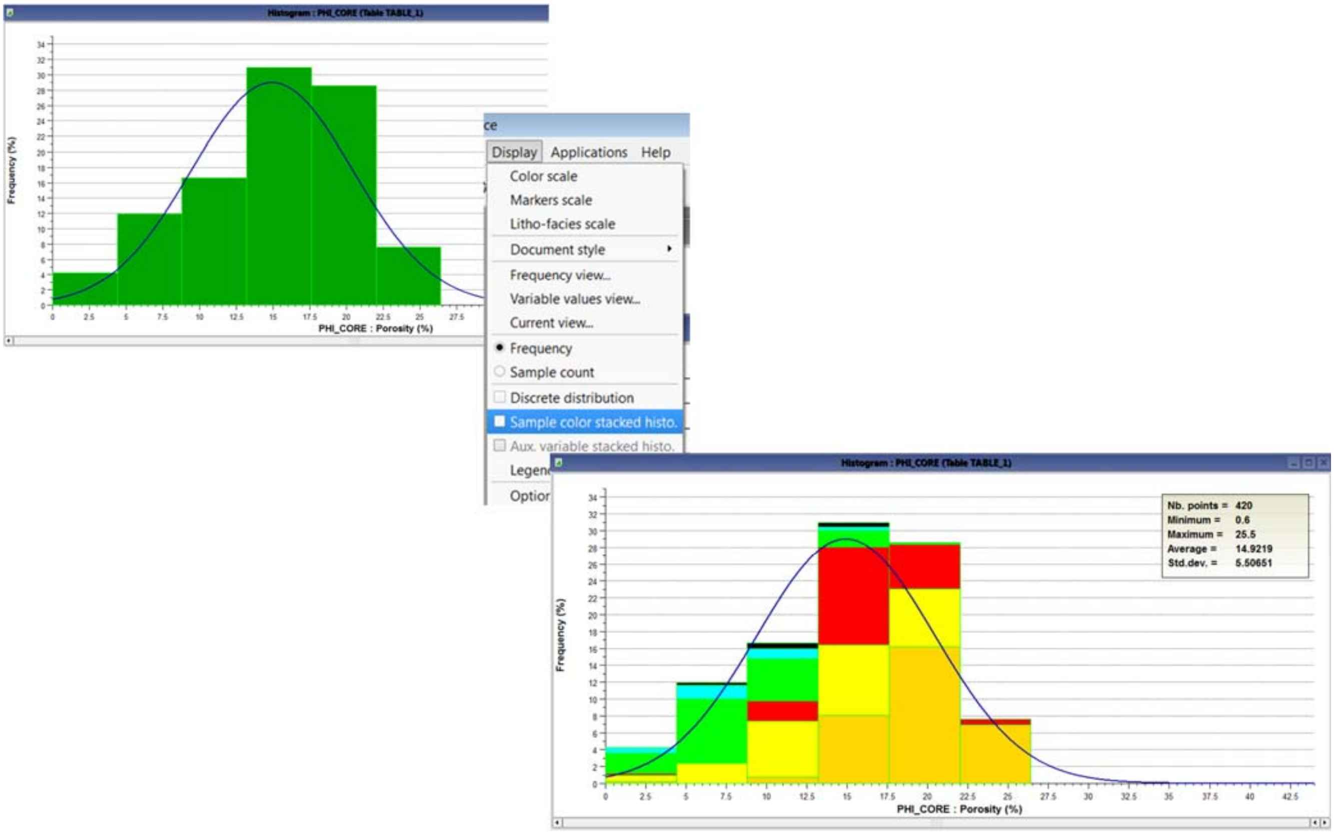








Display statistical distributions (Gaussian)



Petrophysical calibration

Hands-on

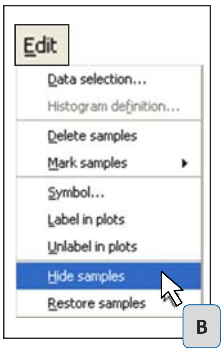
1. **Perform the screenshots and prepare PowerPoint slides to summarize results for each petrofacies and rock type (see RT2)**

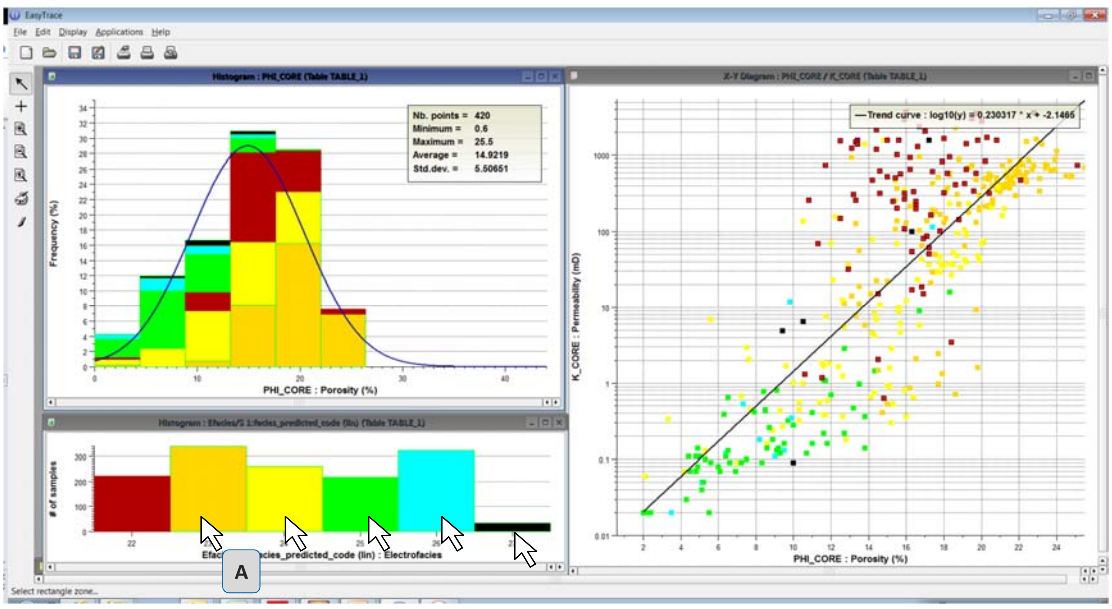
2. **Use transparent paper to draw and discriminate the 6 petrofacies (i.e. Φ/K regression lines)**

3. **Fill in the petrophysical summary table**

Method

- Organize your window (Electrofacies histogram, Porosity core histogram and K-phi XY plot as indicated.
- Select the Electrofacies from 23 to 27 and select → Edit → Hide sample (B)
- Only EF22 points (in red) are displayed

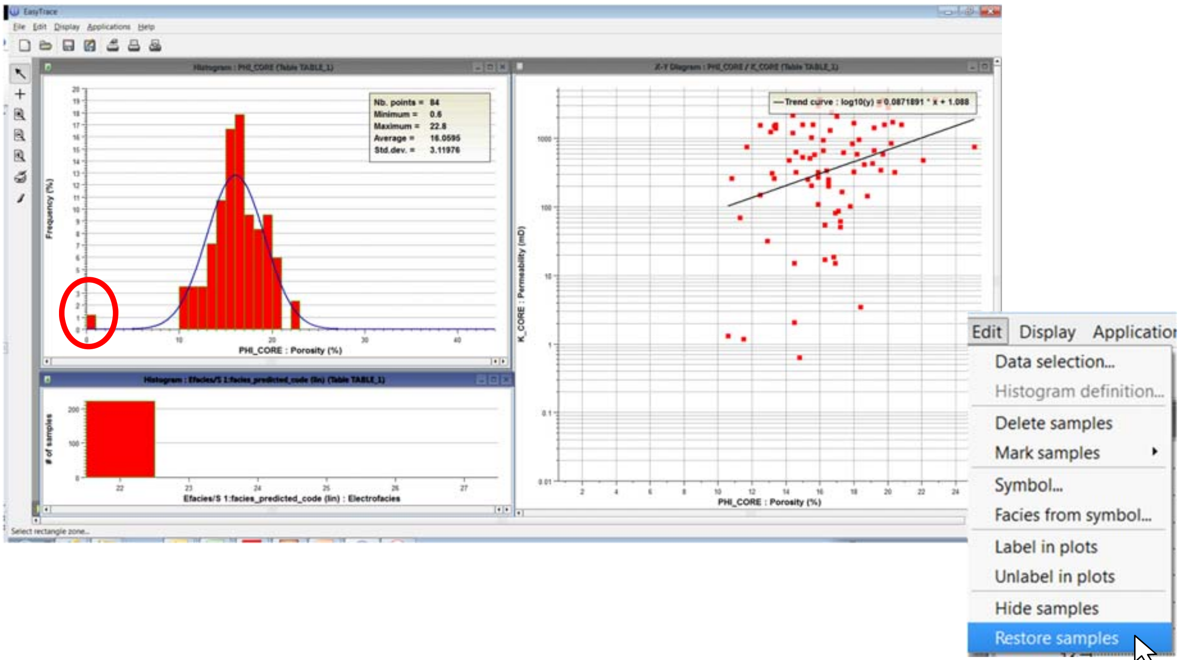




Method

- Hide all samples that do not seen representative of this class (A)
- Write the parameters for Phi and K in the table (next slide)
- Copy and paste on a Power Point slide (screenshot)
- Select Edit → “restore sample”
- Repeat the process for electrofacies (A)

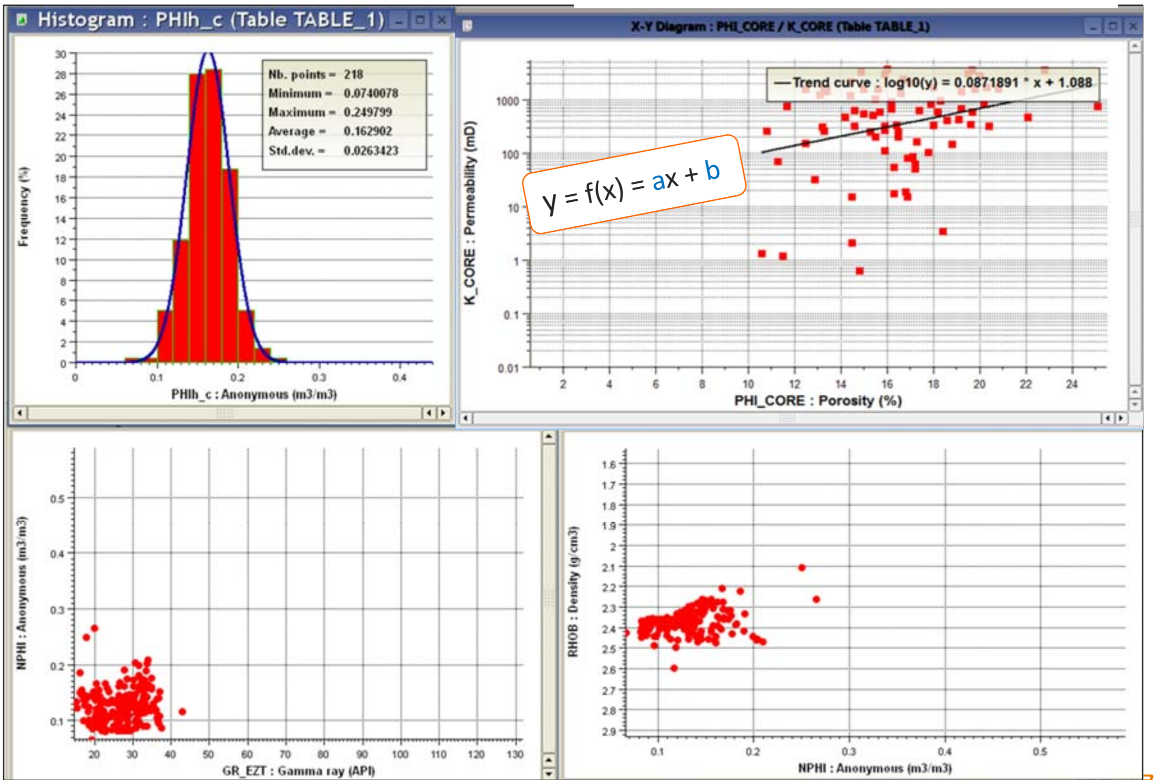
Hide sample



Rock type 2 = RT2

Select Histogram:
Display → Legend box → Statistics
Display → Options → Laws → Draw Gaussian law

Select Cross-Plot (K core vs Phi core):
Compute → add trend curve → Show equation in legend



Petrophysical result summary table

	Clean SS	Radioactive SS	Micaceous SS	Silty shale	Shale	Coal
	EF22	EF23	EF24	EF25	EF26	EF27
PHI min	0.11					
PHI max	0.22					
PHI mean	0.16					
PHI Std. Dev.	2.63				-	-
(K) = 10 (a*PHI+b)	**a** = 0.087 **b** = 1.088	**a** = **b** =	**a** = **b** =	**a** = **b** =	**a** = **b** =	**a** = **b** =

y = f(x) = **ax** + **b**

Rock-types

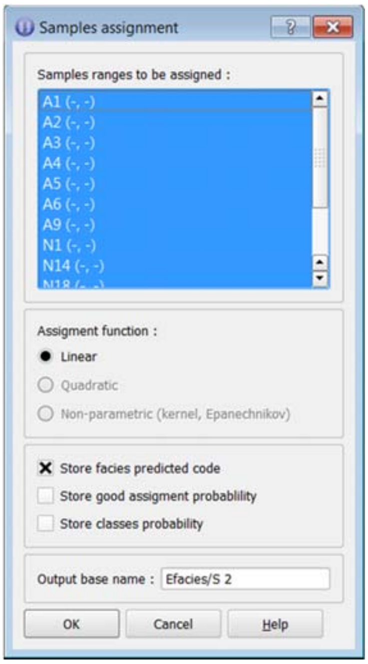
Rock-typing is…

- ***During a conventional study:***
  - *After comparing with cores from others wells (if available), merge electrofacies and/or lithofacies to define Rock-types*
  - *In this simplified case study, each Electrofacies defines a Rock-type*

Rock Types	RT2	RT3	RT4	RT5	RT6	RT7
	Clean SS	Radioactive SS	Micaceous SS	Silty shale	Shale	Coal
	EF22	EF23	EF24	EF25	EF26	EF27

Assign Electrofacies to other wells

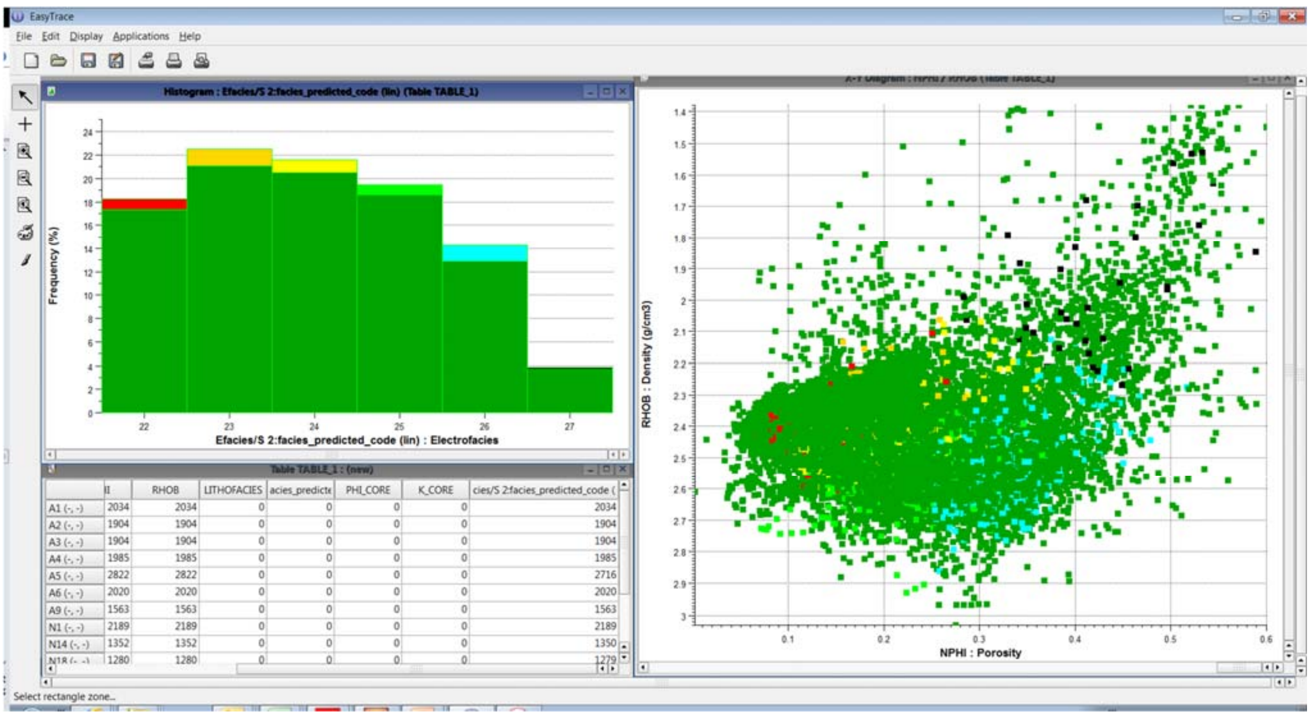
- In the “samples assignment” window, select linear assigment function → OK
- Select → Compute → Assign sample
- Select all the wells and write Efacies/S 2 in the output base name
- OK
- A new column was created with the result in the table



	S	GR	NPHI	RHOB	LITHOFACIES	acies_predicte	PHI_CORE	K_CORE	cies/S 2:facies_predicted_code (
A1 (-, -)	■	2034	2034	2034	0	0	0	0	2034
A2 (-, -)	■	1904	1904	1904	0	0	0	0	1904
A3 (-, -)	■	1904	1904	1904	0	0	0	0	1904
A4 (-, -)	■	1985	1985	1985	0	0	0	0	1985
A5 (-, -)	■	2716	2822	2822	0	0	0	0	2716
A6 (-, -)	■	2020	2020	2020	0	0	0	0	2020
A9 (-, -)	■	1563	1563	1563	0	0	0	0	1563
N1 (-, -)	■	2194	2189	2189	0	0	0	0	2189
N14 (-, -)	■	1350	1352	1352	0	0	0	0	1350
N18 (-, -)	■	1279	1280	1280	0	0	0	0	1279
N2 (-, -)	■	1401	1401	1401	187	1401	420	389	1401
N3 (-, -)	■	2195	2066	2066	0	0	0	0	2066
N9 (-, -)	■	1383	1303	1297	0	0	0	0	1295

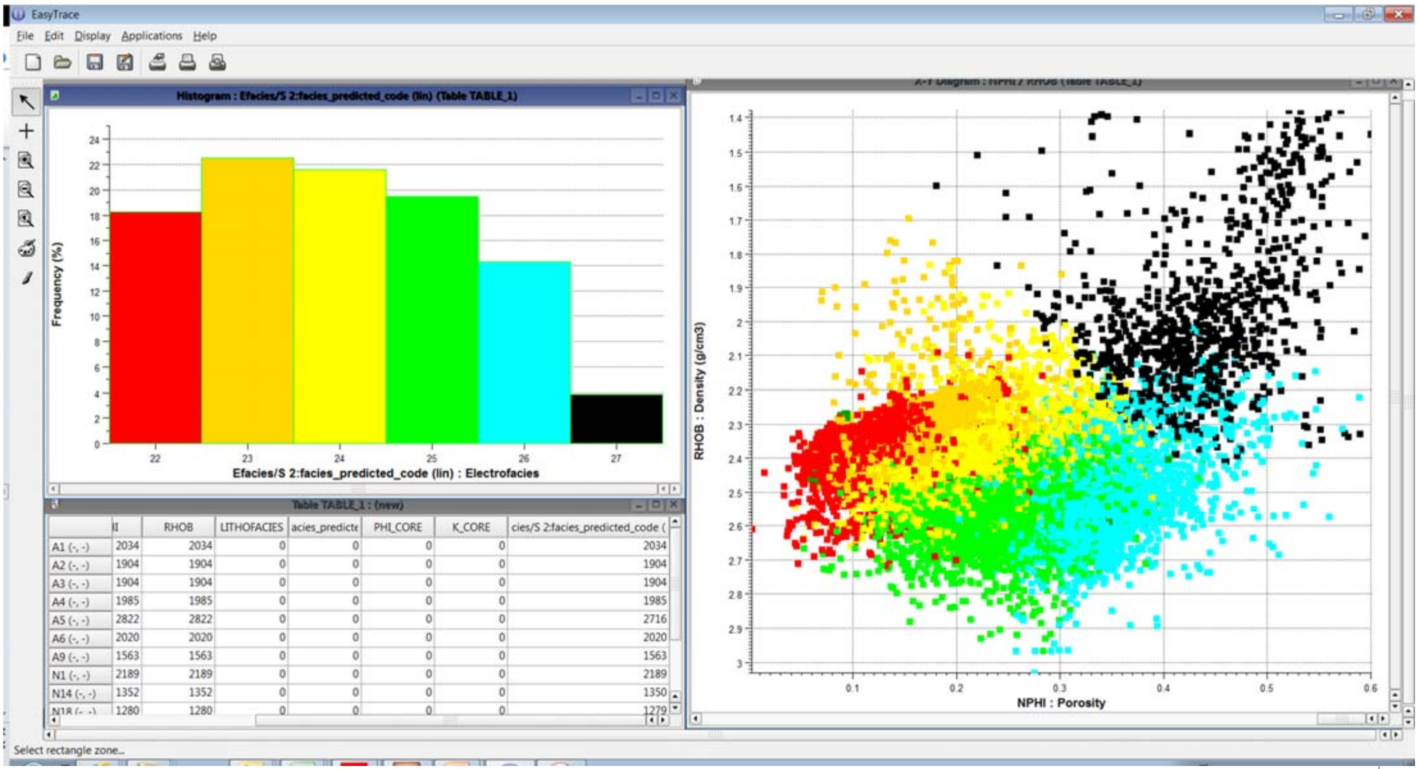
Display global assignment results

- Create NPHI/Rhob plot with all the wells
- Create a histogram for the column “S2 facies predicted code »
- Select the histogram window and display the sample color



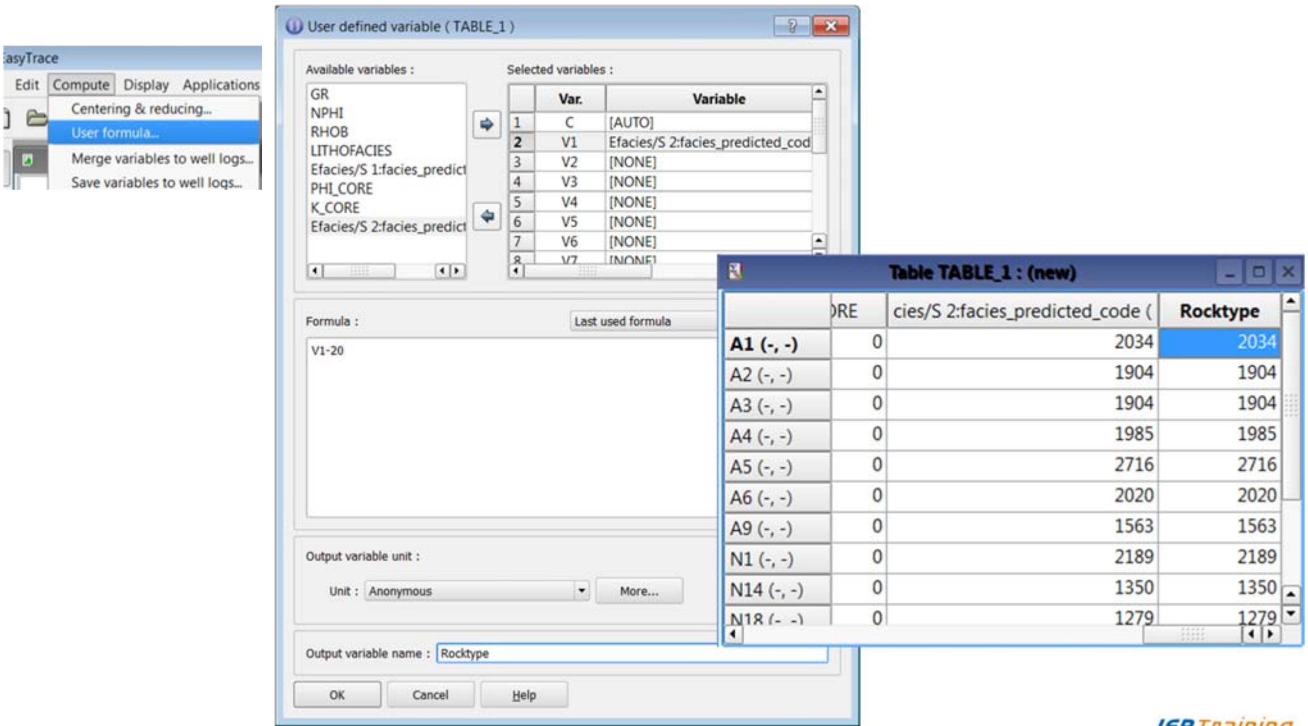
Display global assignment results

- Adjust the color of the histogram bar



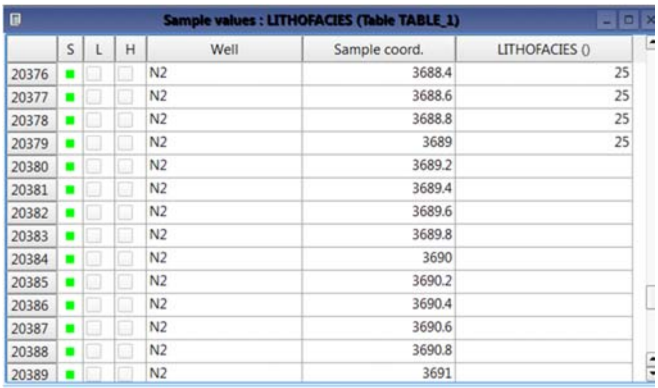
Create Rock-type column

- Select the Table
- Compute – User formula
- Write the formula and output variable name
- The result is displayed in the table window



Supervised approach summary: “Lithofacies”

Rock-type values range between
2 and 7



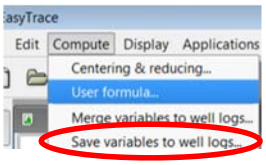
Sample values : LITHOFACIES (Table TABLE_1)

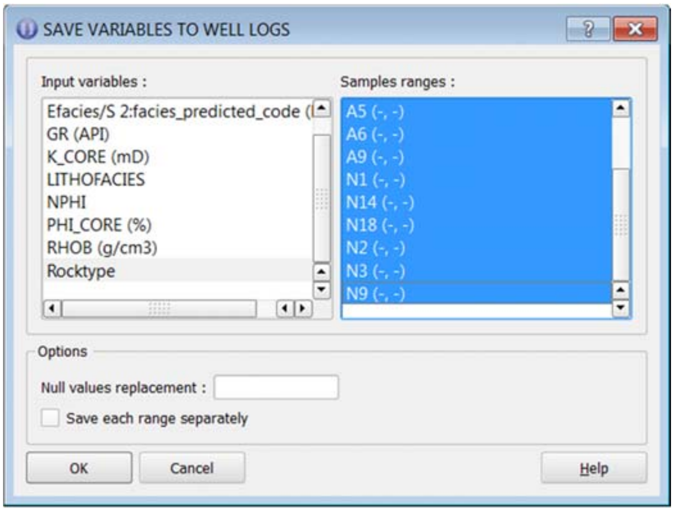
	S	L	H	Well	Sample coord.	LITHOFACIES ()
20376				N2	3688.4	25
20377				N2	3688.6	25
20378				N2	3688.8	25
20379				N2	3689	25
20380				N2	3689.2	
20381				N2	3689.4	
20382				N2	3689.6	
20383				N2	3689.8	
20384				N2	3690	
20385				N2	3690.2	
20386				N2	3690.4	
20387				N2	3690.6	
20388				N2	3690.8	
20389				N2	3691	

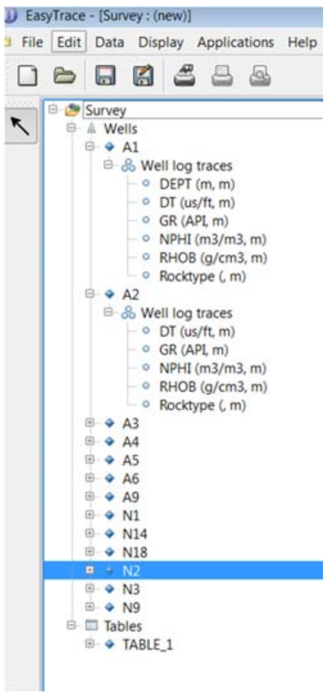
```
3433.80005 6
3434.00000 6
3434.19995 6
3434.39990 6
3434.60010 6
3434.80005 6
3435.00000 6
3435.19995 6
3435.39990 6
3435.60010 6
3435.80005 6
3436.00000 6
3436.19995 6
3436.39990 6
3436.60010 6
3436.80005 5
3437.00000 4
3437.19995 2
3437.39990 2
3437.60010 2
3437.80005 3
3438.00000 3
3438.19995 3
3438.39990 3
3438.60010 3
3438.80005 3
3439.00000 3
3439.19995 3
3439.39990 3
3439.60010 3
3439.80005 3
3440.00000 3
3440.19995 3
3440.39990 3
3440.60010 3
3440.80005 2
3441.00000 2
```


Generate a rock-type log

- Select the Table
- Compute – Save variables to well logs
- Select the Rock-type and all the wells
- The result is displayed in the Survey window – The Rock-type log is now available for export



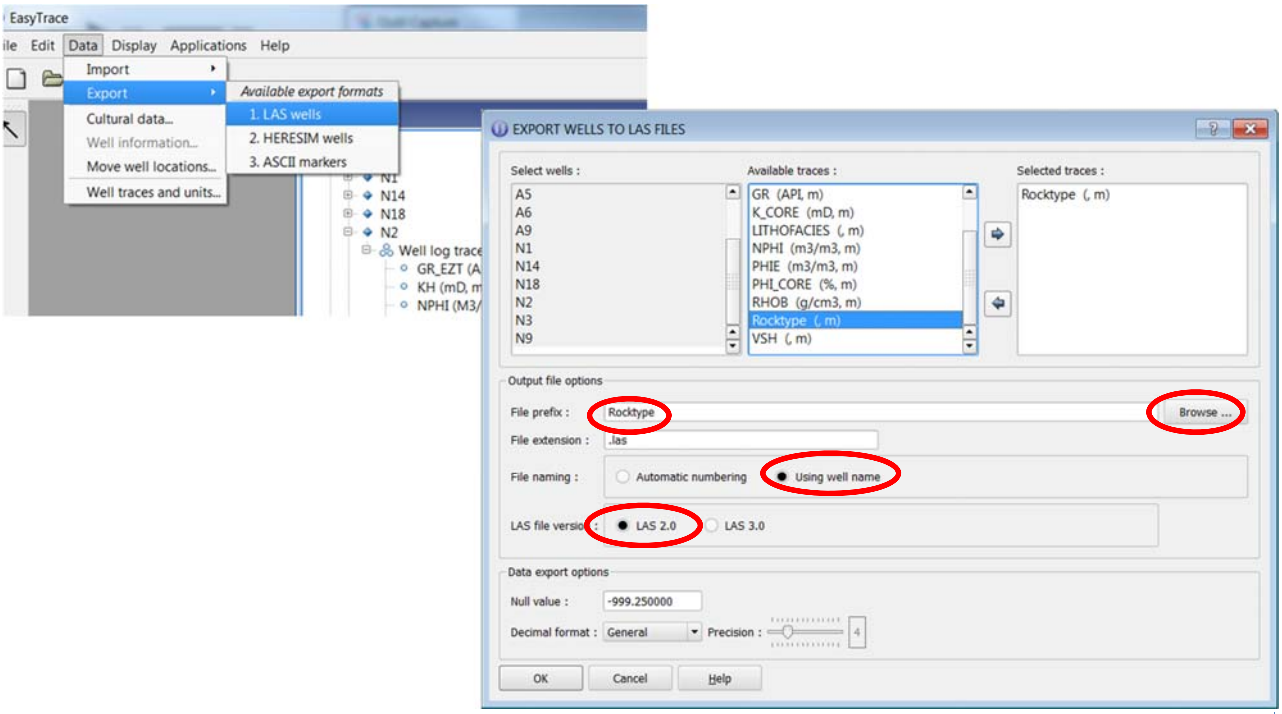




Export rock-types in “LAS” file

Export Rock Type log

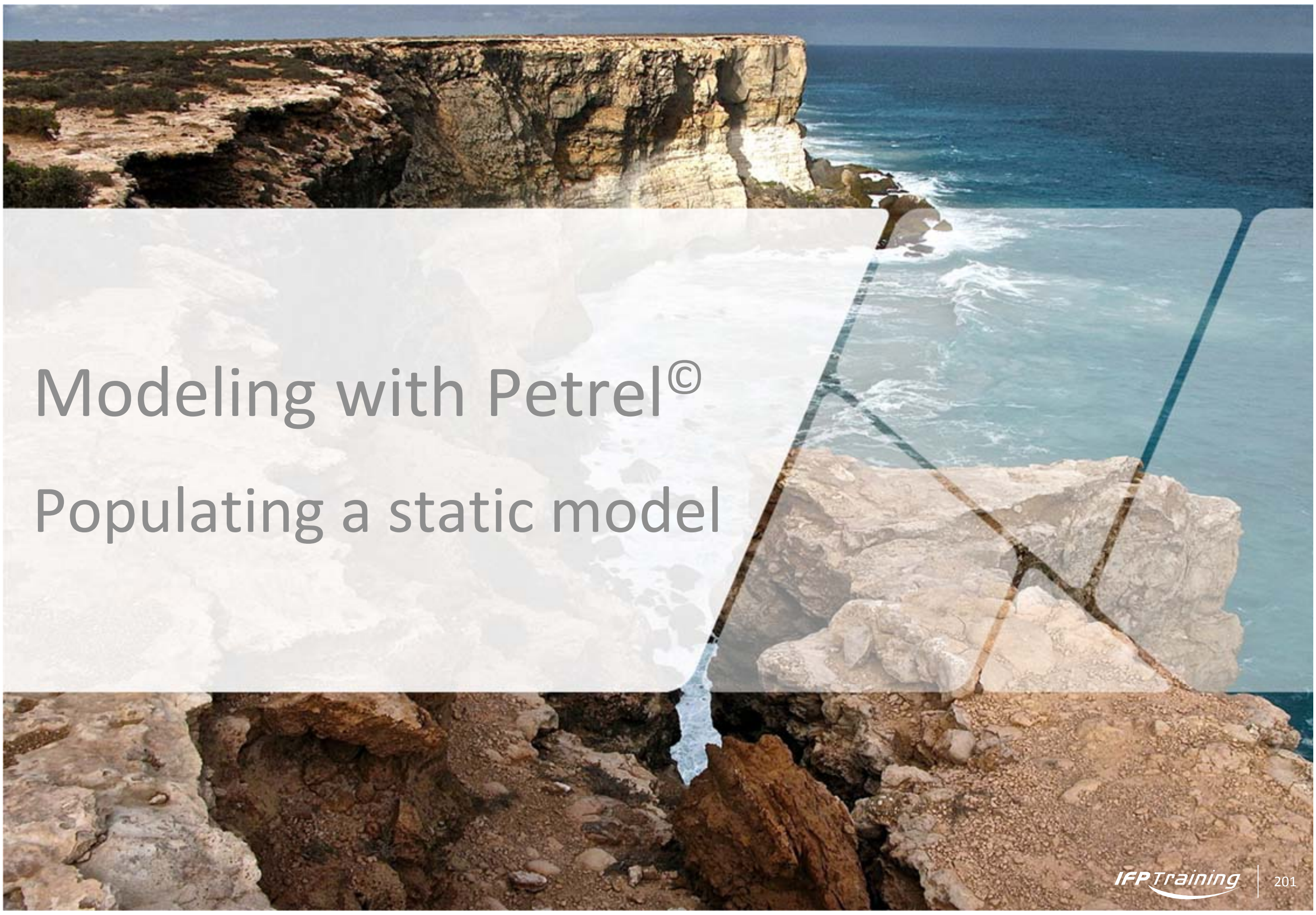
- Select the Survey window
- Data → Export → LAS wells



4. Properties modeling

Chapter 4 - Summary

- **Properties modeling *(Petrel©)***
  - Sedimentological modeling
    - Rock type modeling
    - Facies modeling
  - Petrophysical modeling
  - Fluid modeling and volumetrics
  - Towards flow simulation (upscaling)

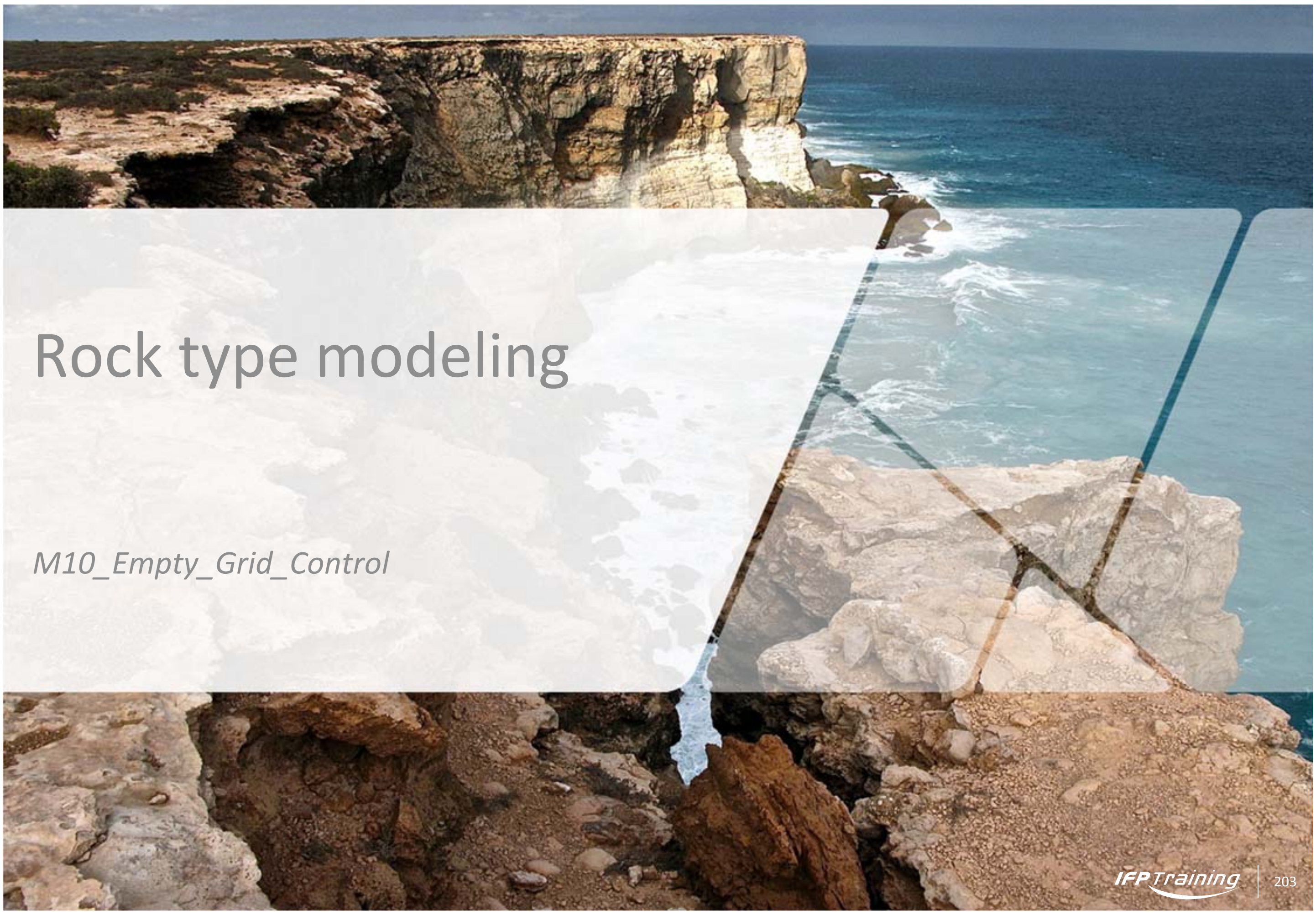


Modeling with Petrel©

Populating a static model

Summary

- **Rock type modeling**
- **Facies modeling**
- **Petrophysical modeling**
- **Fluids modeling and volumetrics**
- **Towards flow simulation** (upscaling)
- **Final results presentation**

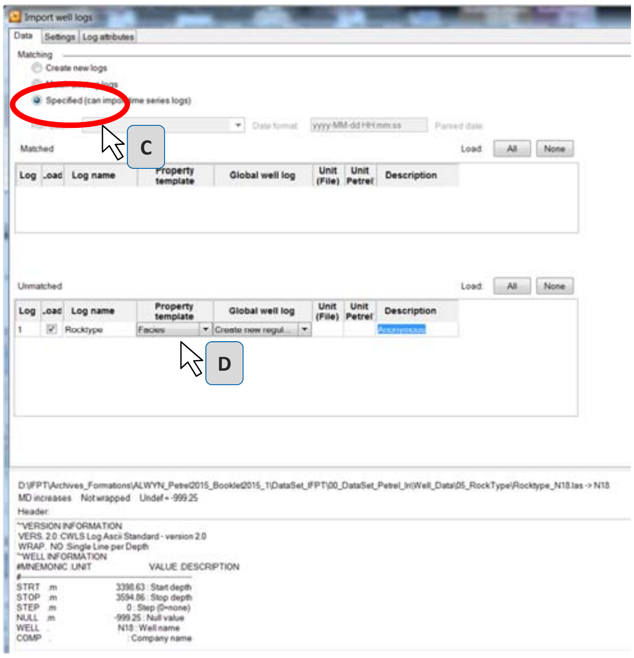


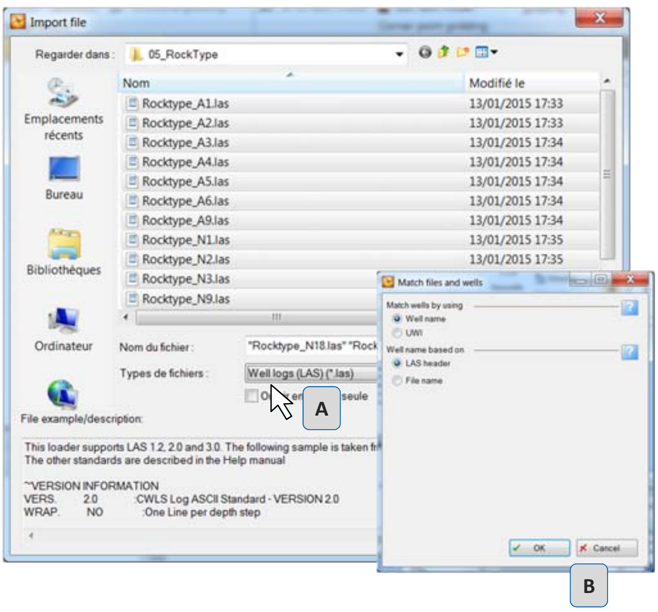
Rock type modeling

M10_Empty_Grid_Control

Load Rock-type log from Easy Trace survey

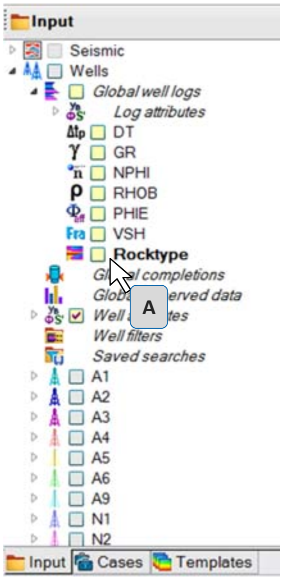
- Input Tab must be selected
- Import file using “well log” (*.LAS) format (A)
- Panel “Match files and wells” – OK (B)
- Import well log window:
  - Select specified (C)
  - Choose “Facies” (D)

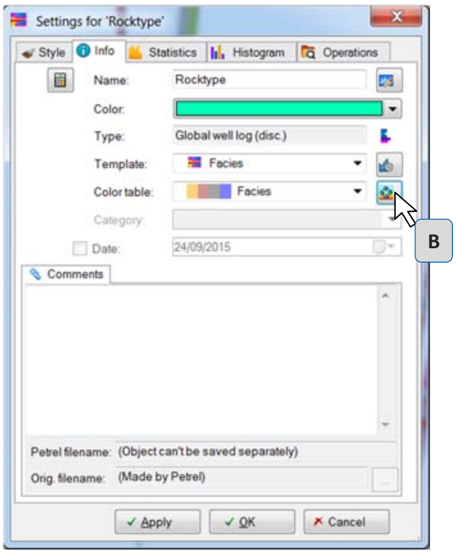




Define the facies color

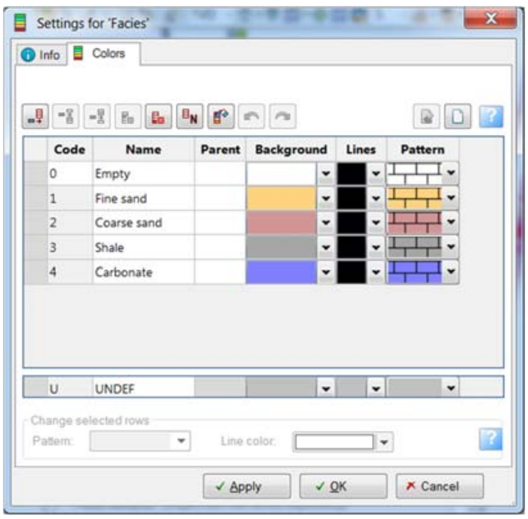
- Visualize “Rock-type”
  - Develop Global well logs
  - Right click for settings (A)
  - Select the icon (B)

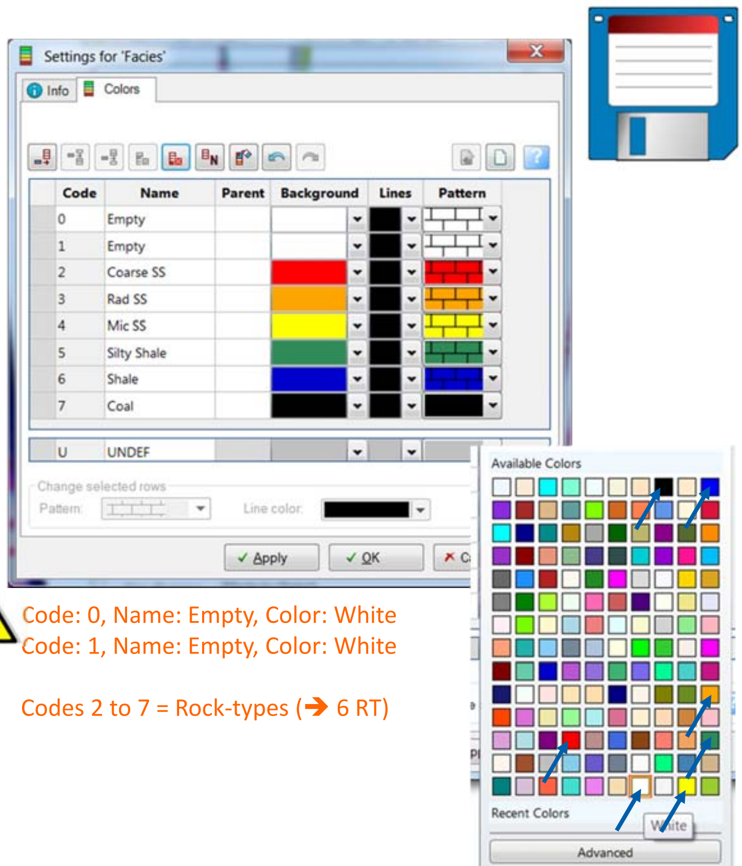




Define the facies color - M11_Rocktype_Loaded

- Visualize “Rock-type”
  - Develop Global well logs
  - Right click for settings (A)
  - Select the icon (B)



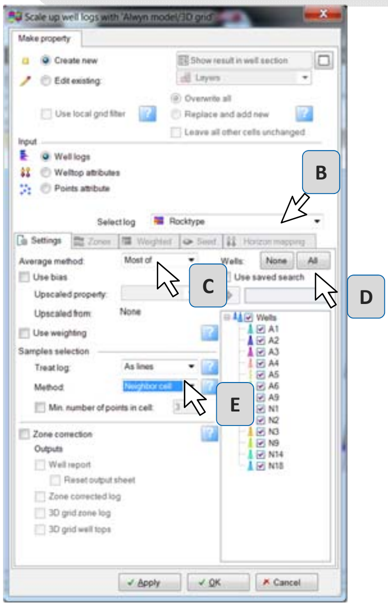


Code: 0, Name: Empty, Color: White
Code: 1, Name: Empty, Color: White

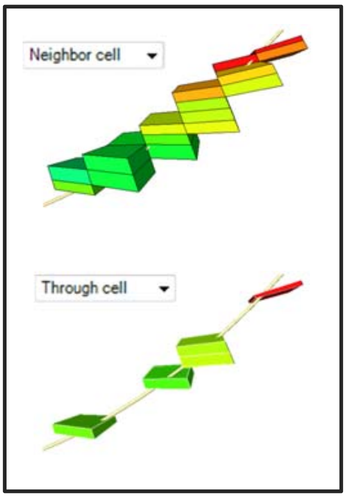
Codes 2 to 7 = Rock-types (➔ 6 RT)

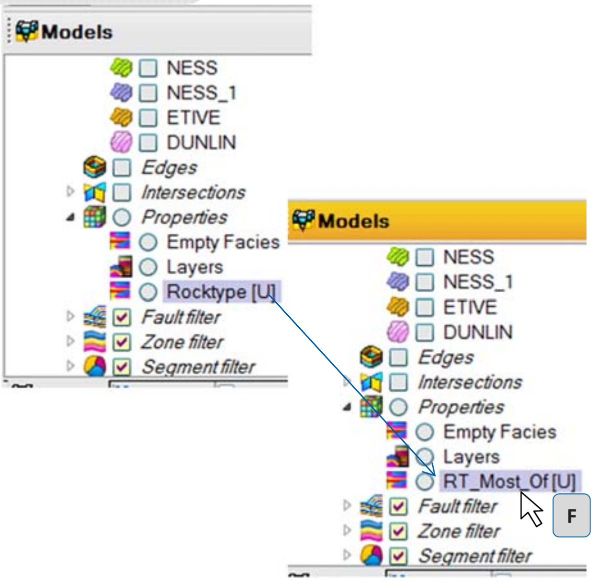
Scale up well logs – Most Of

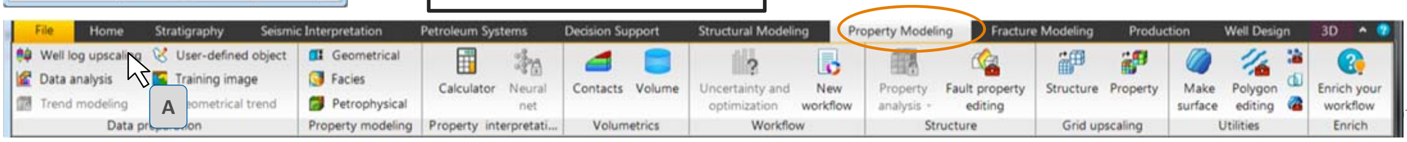
- **Upscale facies from well-log resolution to grid resolution**
  - Select “Well log upscaling” in the Property Modeling ribbon (A)
  - Choose “Rocktype” log in the “Select logs” window (B)
  - Choose “Most of” average method (C). “Most of “ (most represented value) and select wells “All” (D)
  - Select “Neighbor cell” (E)
  - Rename “Rocktype” property as “RT_Most_Of” (F)



The method generally used is “Neighbor cell”, the result is only changing for highly deviated wells (C)

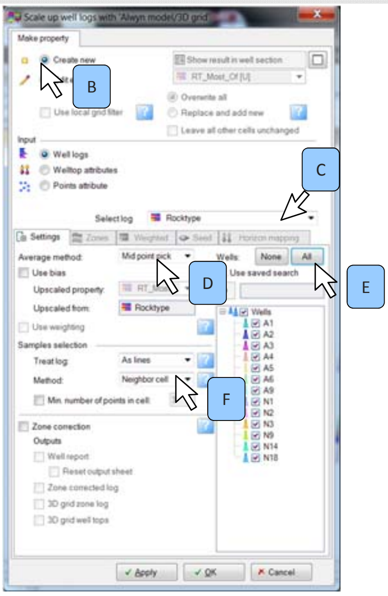


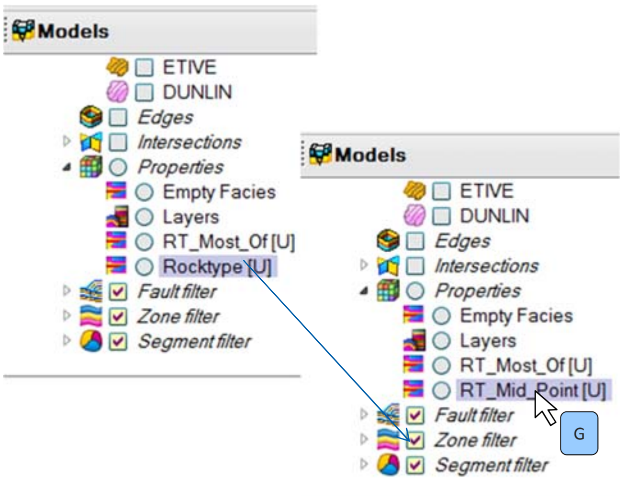




Scale up well logs – Mid point

- **Upscale facies from well-log resolution to grid resolution**
  - Select “Well log upscaling” in the Property Modeling ribbon (A)
  - Select “Create new” (B) and choose “Rocktype” log in “Select logs” window (C)
  - Choose “Mid point pick” average method (D) and select wells “All” (E)
  - Select “Neighbor cell” (E)
  - Rename “Rocktype” property as “RT_Mid_Pointf” (G)



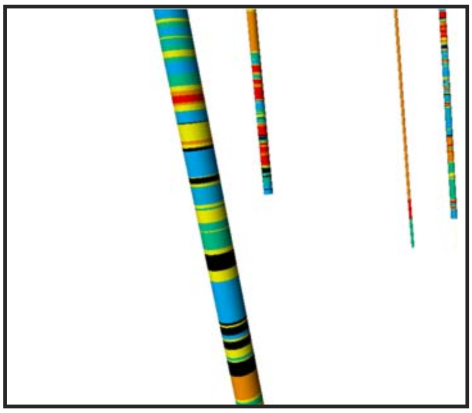


Scale up well logs

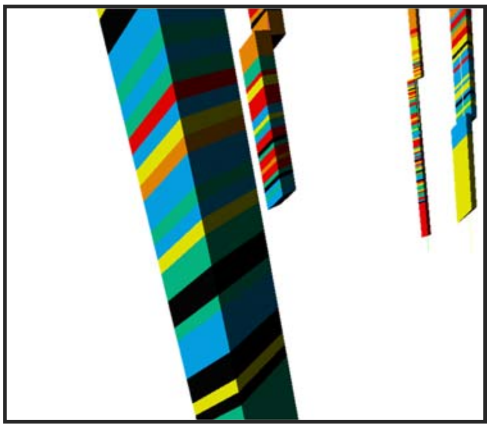
Visualize the results in “Models”:
Properties, Most_Rocktype (U),
Mid_Rocktype (U) *[Upscaled]*

“Most_Of” after upscaling

Raw data

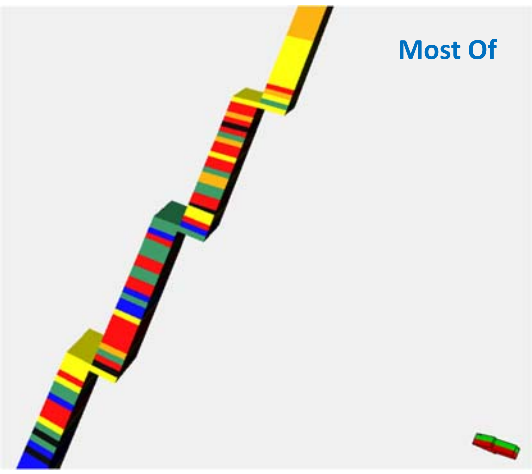


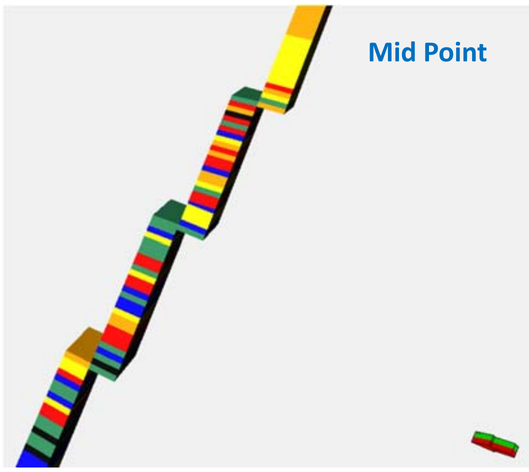
“Mid point” after upscaling



Scale up well logs

- **Observe the differences**





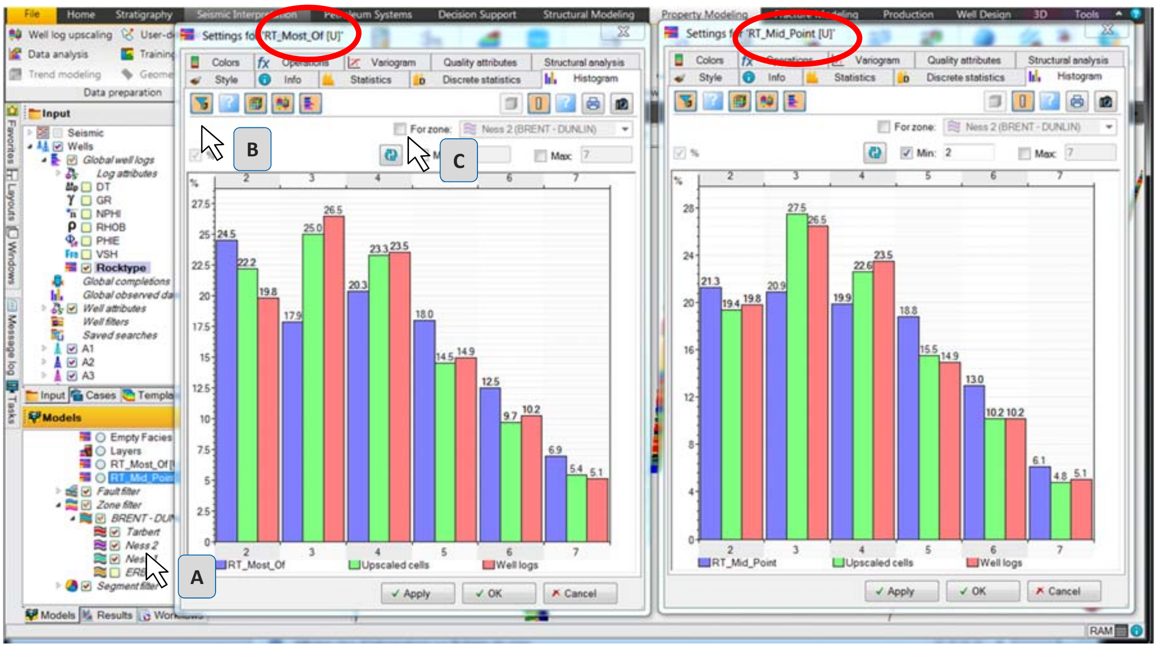
Scale up well logs

- **Use a histogram to determine the best algorithm for upscaling**
  - Select RT property and settings → histogram
  - Use the zone filter and select Tarbert, Ness 2 and Ness 1 (A)
  - Click on filter (B) and Unselect "For zone" (C)

→ Evaluate the impact of upscaling

→ Go back to layering

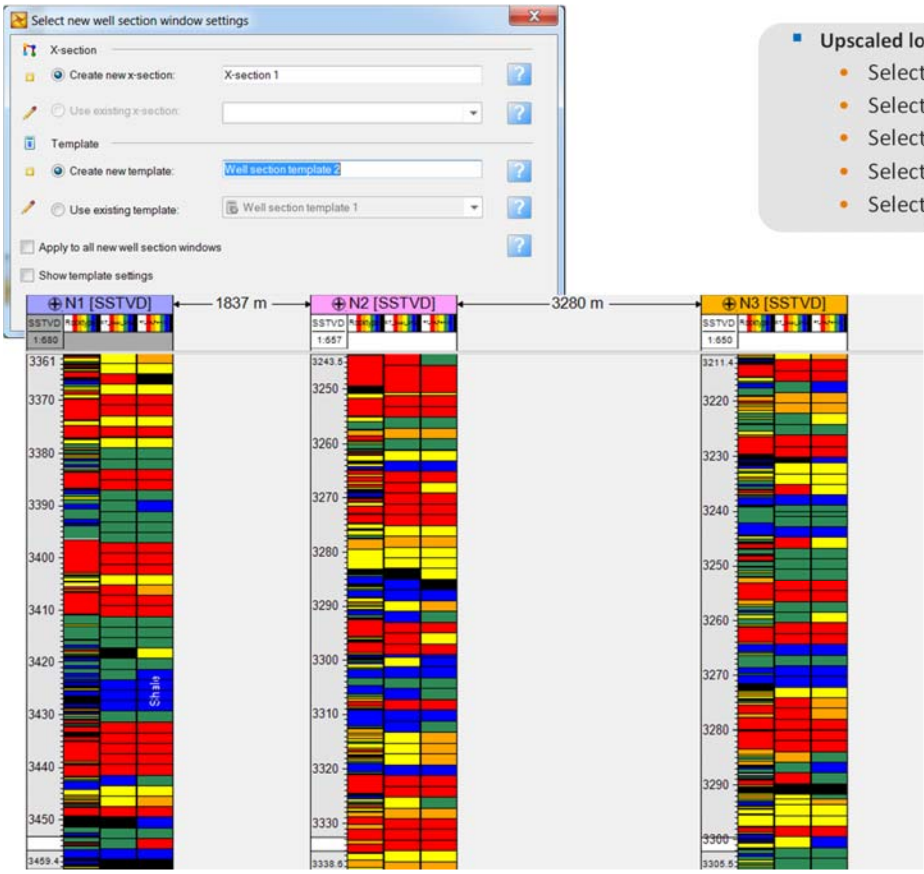
To control if the chosen algorithm is representative of the well log data:
- Create different properties with different algorithms and compare the electrofacies proportions with the initial proportions.
- If differences between "Upscaled cells" vs. "well-log" bars are too big → the algorithm is not representative and/or the layering is too thick, go back to "layering" process (Iterative process).



Scale up well logs

Mid point pick

Upscaled logs QC

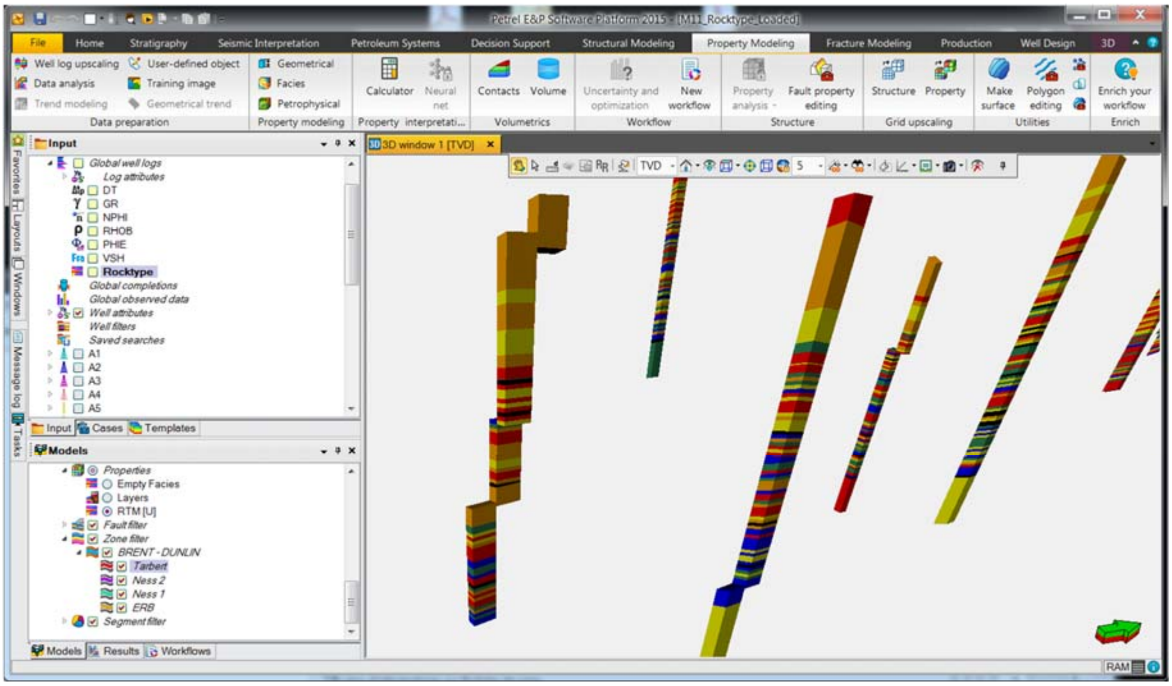


- **Upscaled logs QC**
  - Select window → New well section window
  - Select input index and choose wells
  - Select Input → Rocktype
  - Select model window
  - Select Properties RT_Most_Of and RT_Mid_Point

Upscaled logs – Clean your data

- **Upscaled logs QC**
  - In Model panel select the Property you consider as the most reliable after your QC (RT_Mid_Point)
  - Rename this property as "RTM" (**R**ock**T**ype **M**odel to simplify the name for calculation in Petrophysical modeling)
  - Delete the unselected property

M12_Rock_Type



Facies modeling

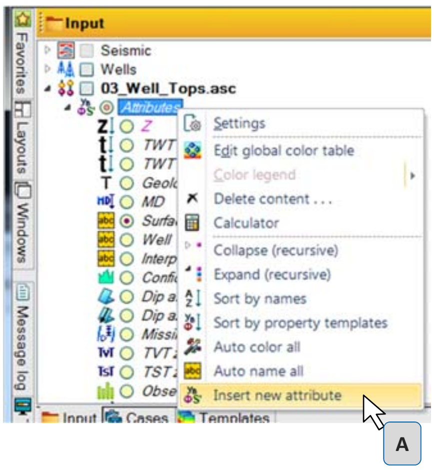
Sedimentological characterization Hands-on

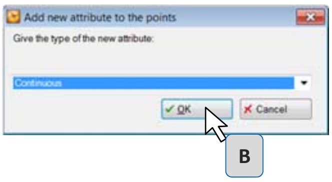
- → Hands-on practice HOP #3 (Appendix)
- → Back to Petrel after exercise

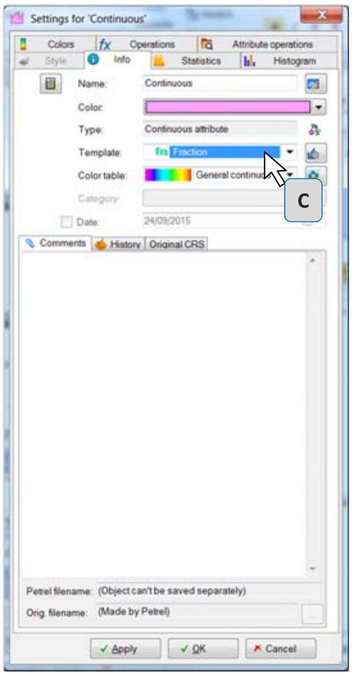
M12_Rock_Type

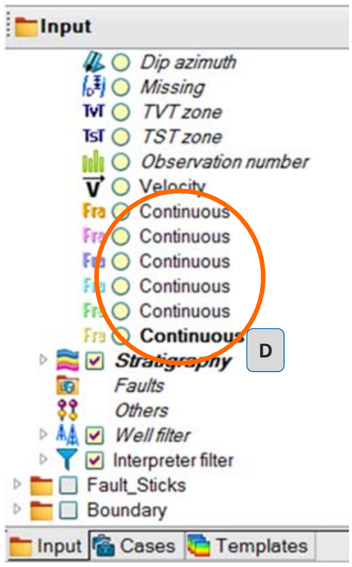
Pie-chart diagram – Facies percentage

1. **Create a new attribute to represent facies percentage by zone.**
   - Right click on marker attribute in the input window and “insert a new attribute” (A)
   - Select attribute type as continuous (B)
   - Change template to “Fraction” (C)
   - Repeat 6 times (6 Continuous attributes are needed) (D)



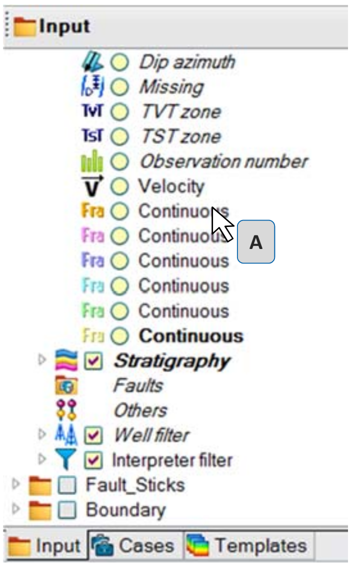


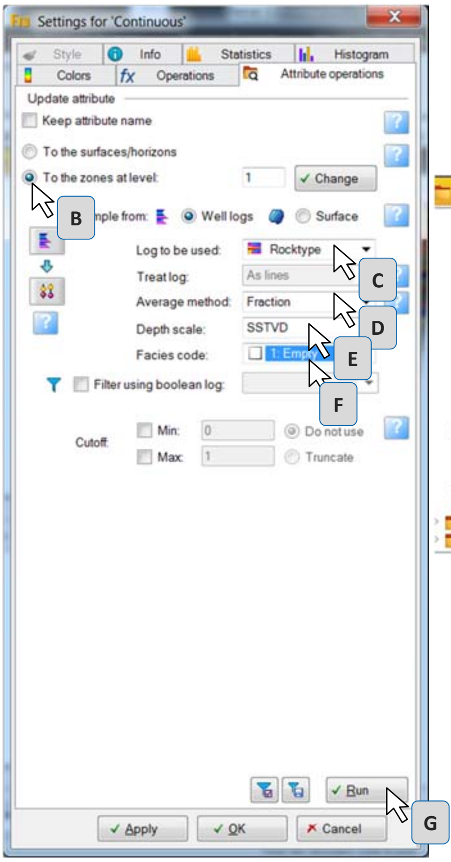


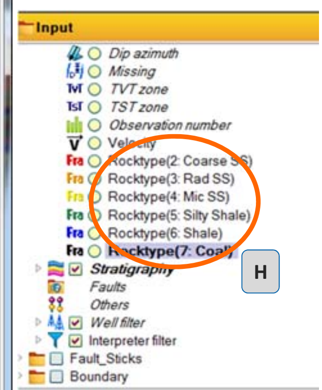


Pie-chart diagram – Facies percentage

2. **Create a new attribute:**
   - Select Continuous attribute (first one) (A)
   - Settings – Attribute operations tab
   - Select “To the zones”: at level (B)
   - Select Facies log (C), average method as fraction (D)
   - Select Depth scale TVDSS (E) and Facies code (F)
   - Run (G)
   - Redo for the others facies (see the result on (H))



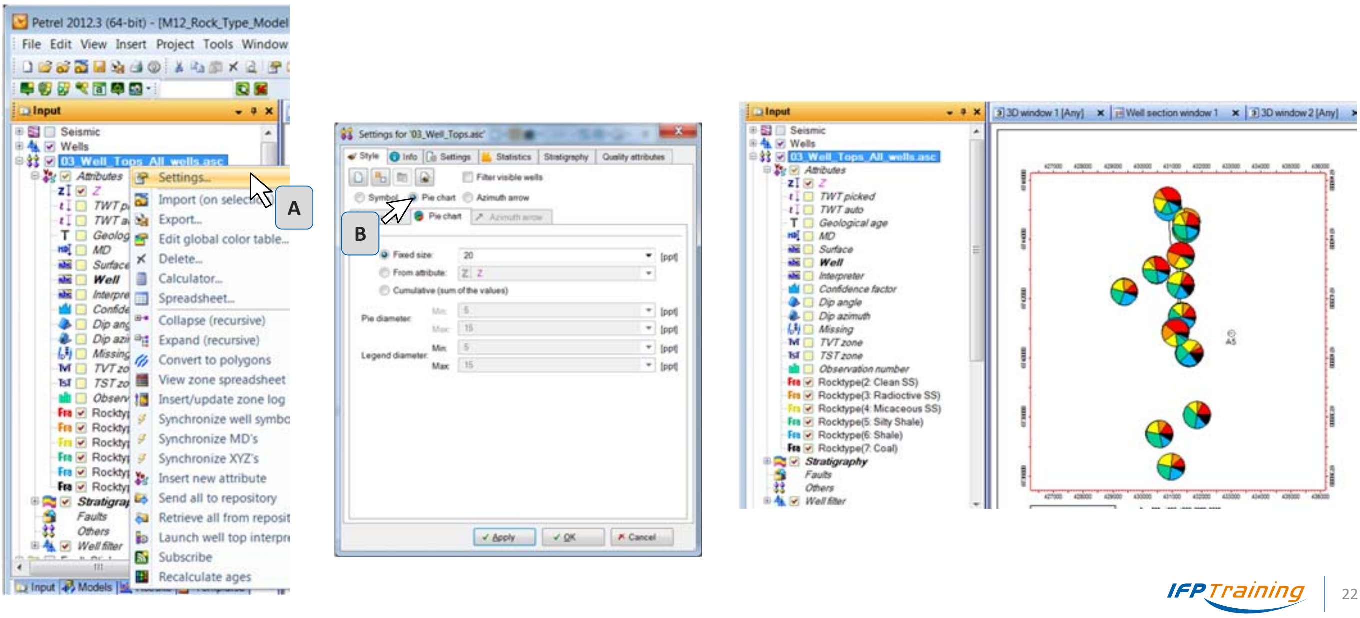




Pie-chart diagram – Display

3. Display the pie chart

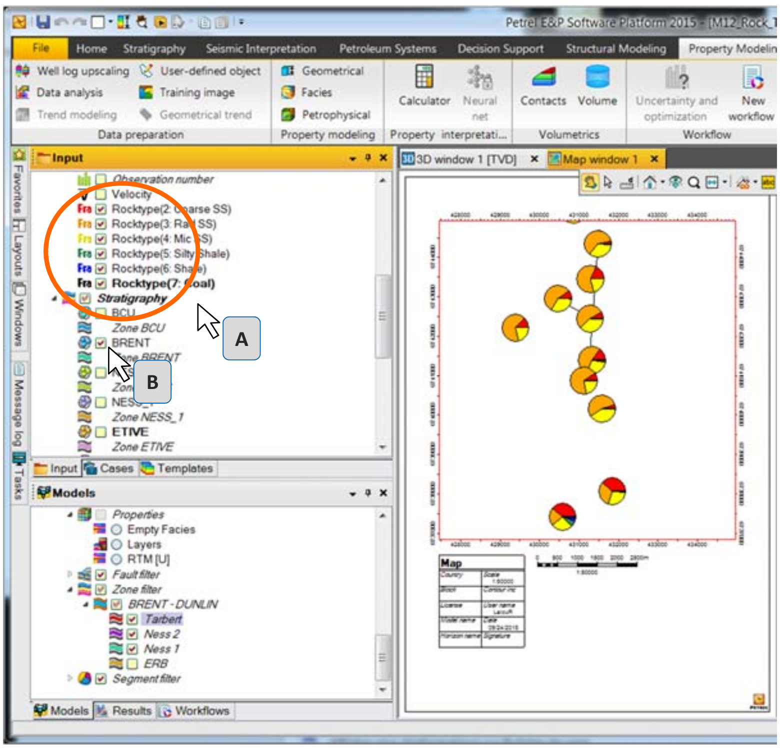
- Open a new Map window
- Select “Well tops” → “Settings” (A) → “Style”
- Select “Pie chart” (B), (“Pie chart” button is only active if a Map or an intersection window is open)
- The lowest panel allows to resize the pie



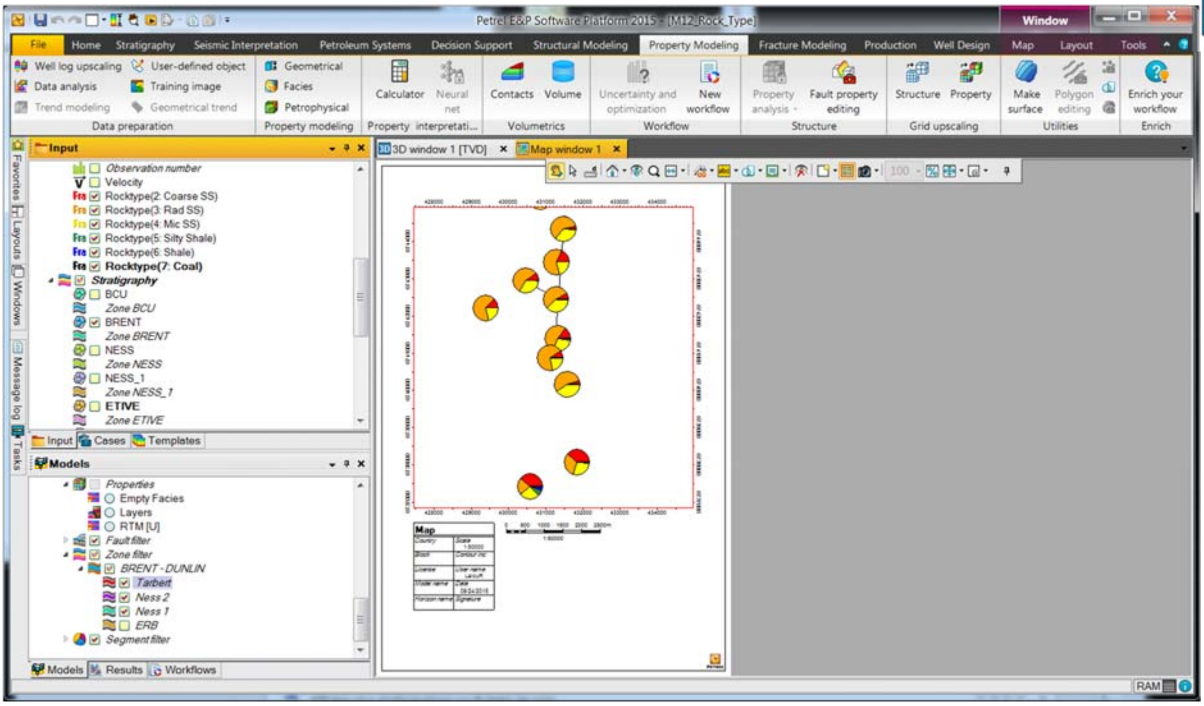
Pie-chart diagram – Display

4. Display pie charts

- Select Attributes (A) and Zone (B)
- Adjust the pie size in “well tops” → “Settings” → “Style” → “Size → “20”

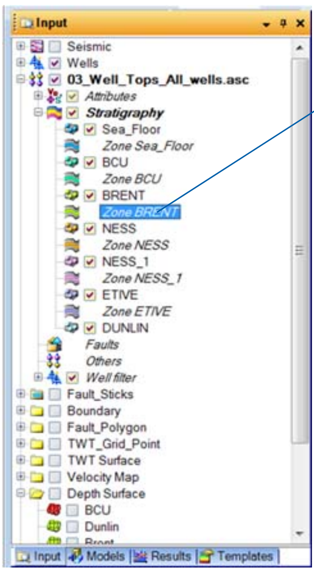


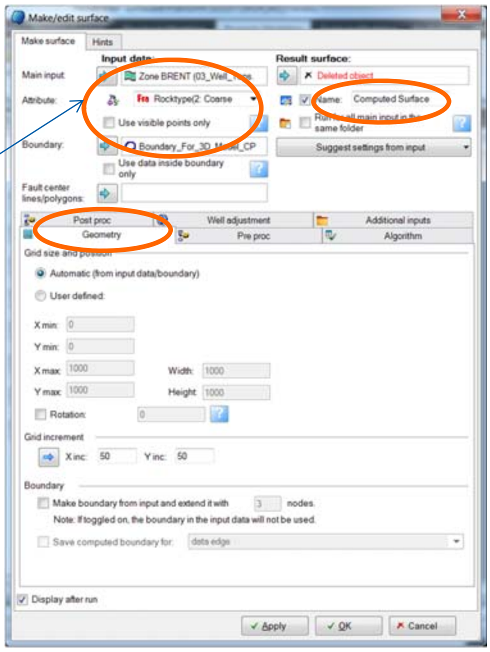
M13_Pie_Chart

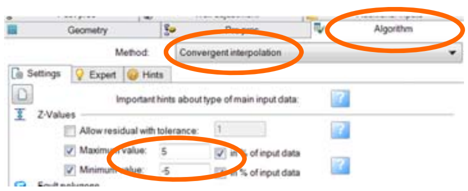


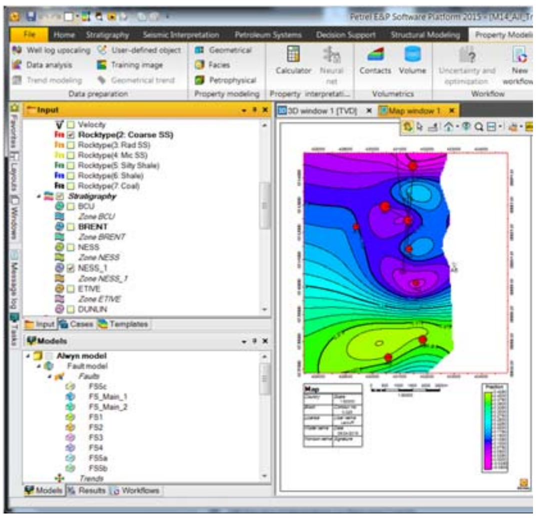
From facies proportion to facies map

- **Create Facies map**
  - Property Modeling Ribbon → Make surface
  - Fix “zone”, “attribute” and “Boundary” as shown below
  - Rename resulting surface
  - Select “Convergent interpolation” method with a clipping Z-values at – 5/5%

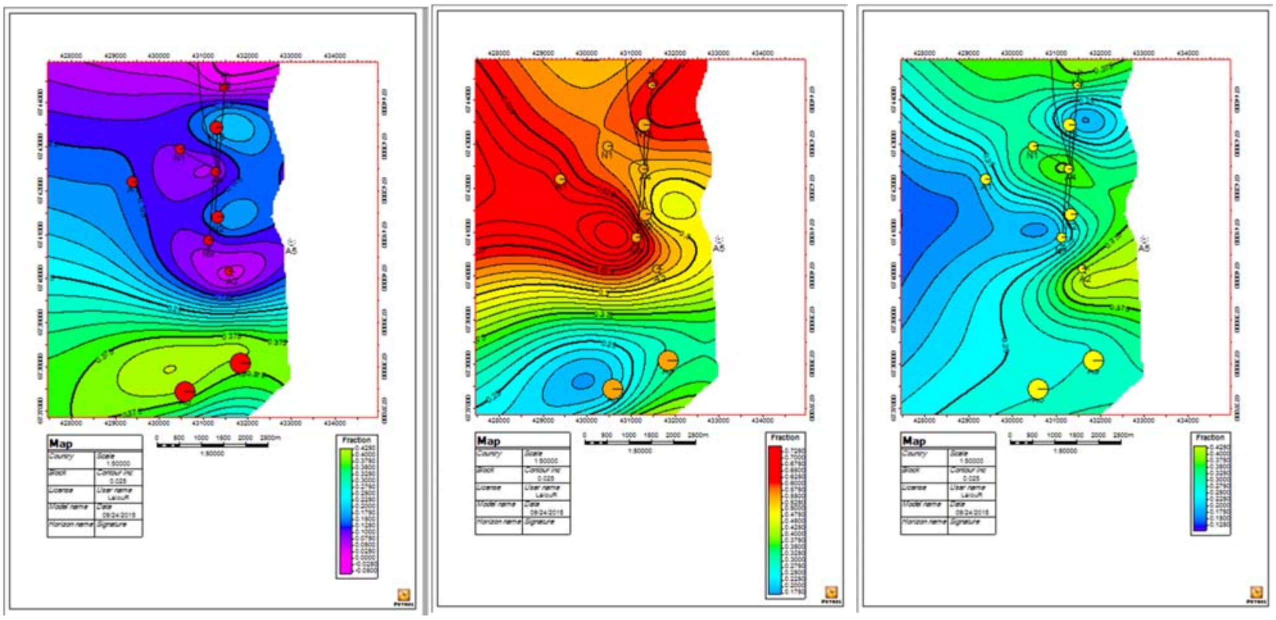




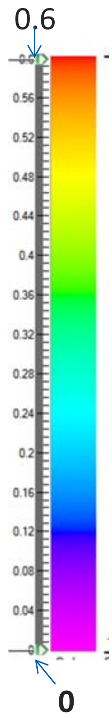




Trend maps for facies modeling – Tarbert

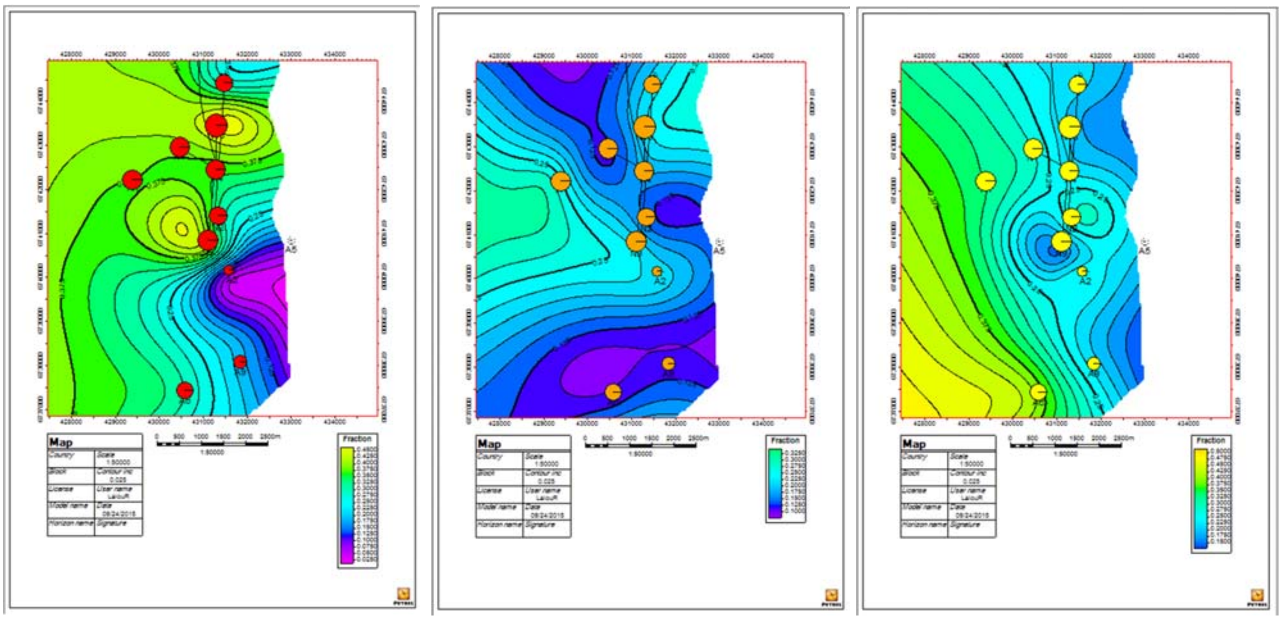


Clean_SS **Radioactive_SS** **Micaceous_SS**

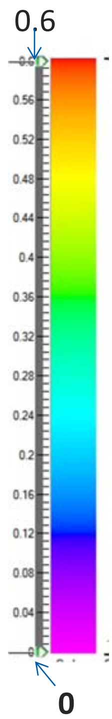


No maps computed for Silty Shale, Shale and coal.
These facies are used as adjustment variable

Trend maps for facies modeling – Ness 2

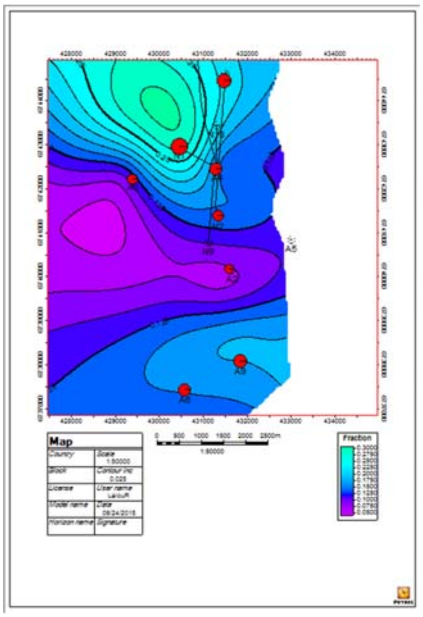


Clean_SS **Radioactive_SS** **Micaceous_SS**

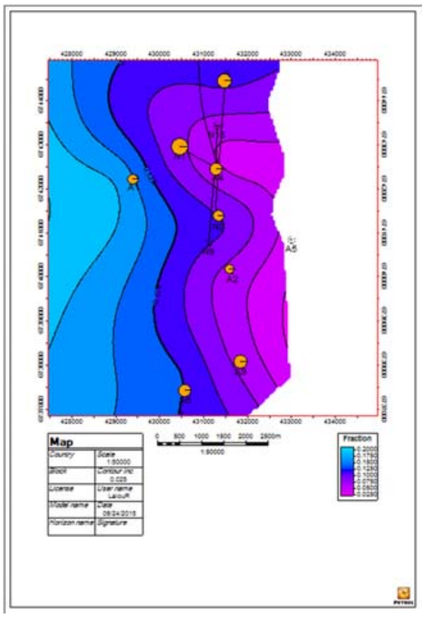


No maps computed for Silty Shale, Shale and coal.
These facies are used as adjustment variable

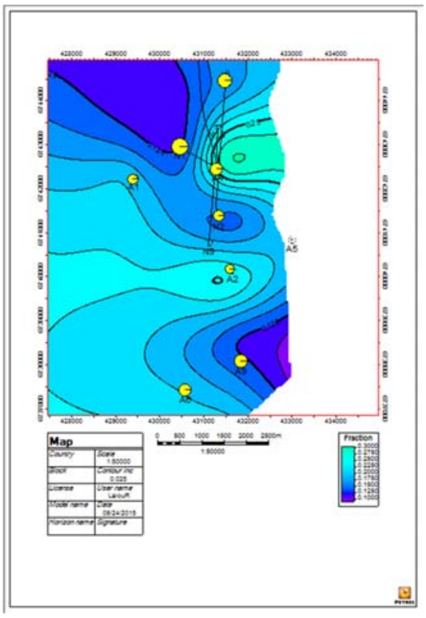
Trend maps for facies modeling – Ness 1



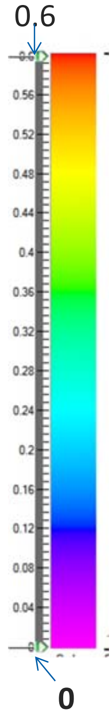
Clean_SS



Radioactive_SS

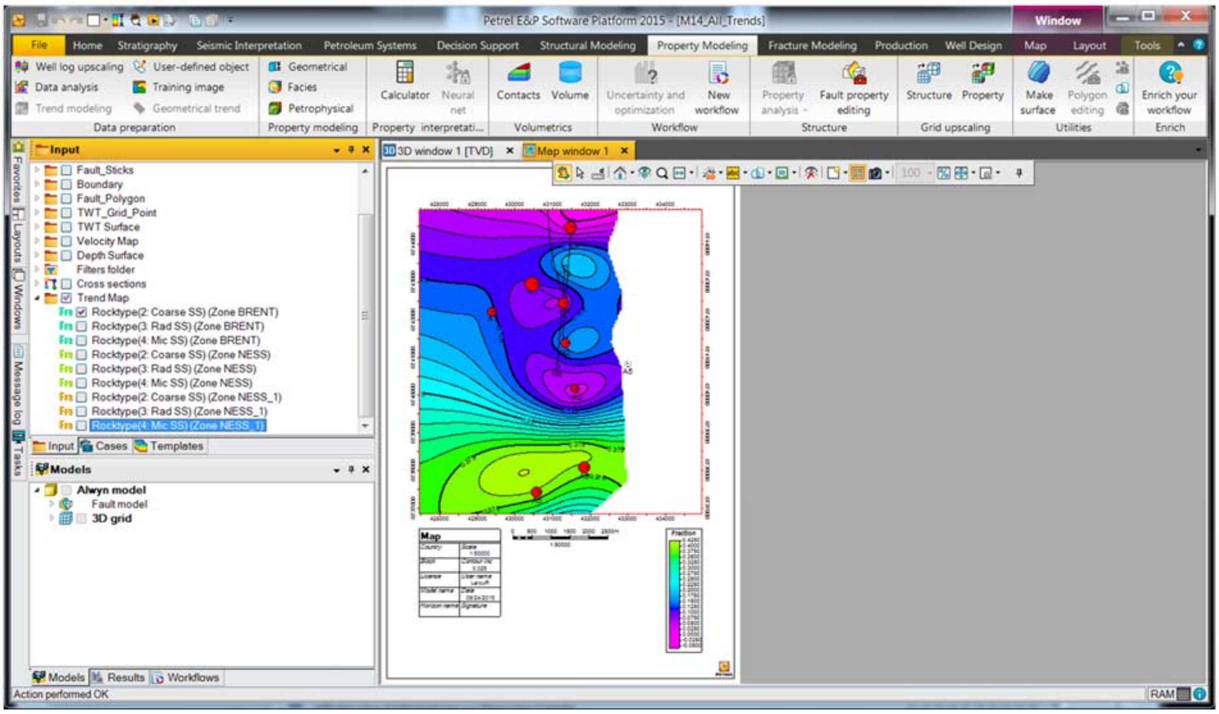


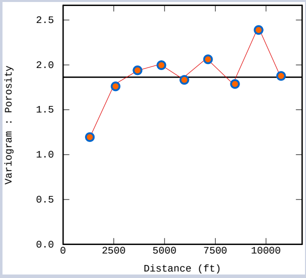
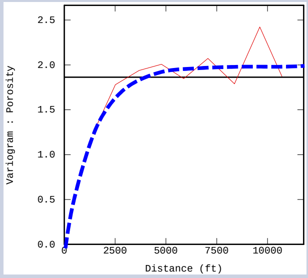
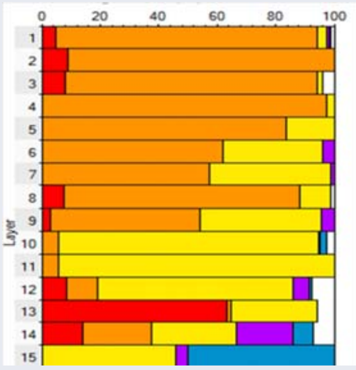
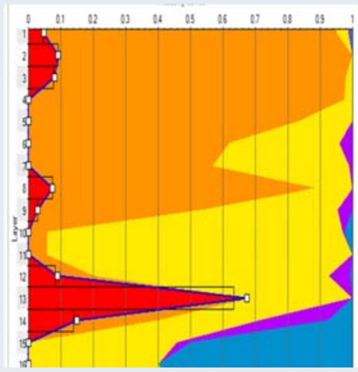
Micaceous_SS



No maps computed for Silty Shale, Shale and coal.
These facies are used as adjustment variable

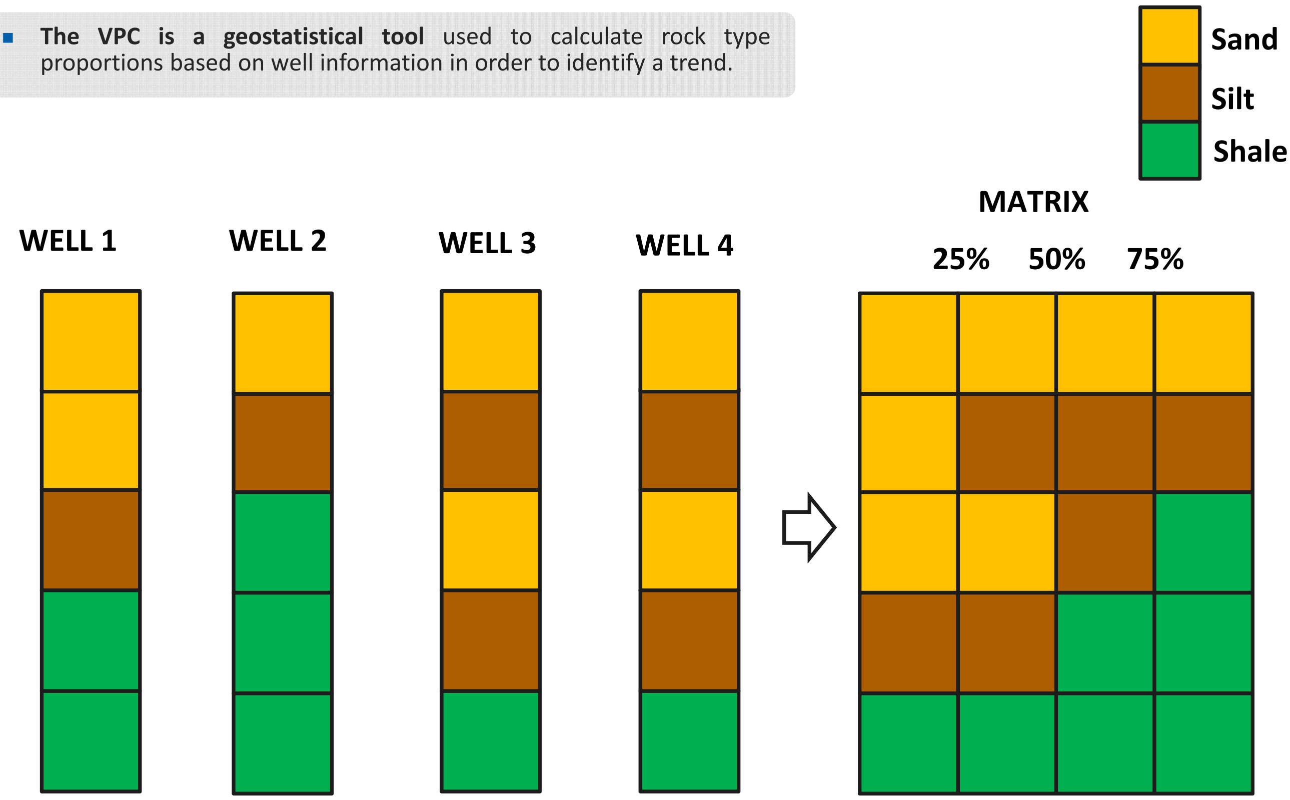
M14_All_Trends



	Characterization	Modeling
Variograms		
Vertical Proportion Curves		

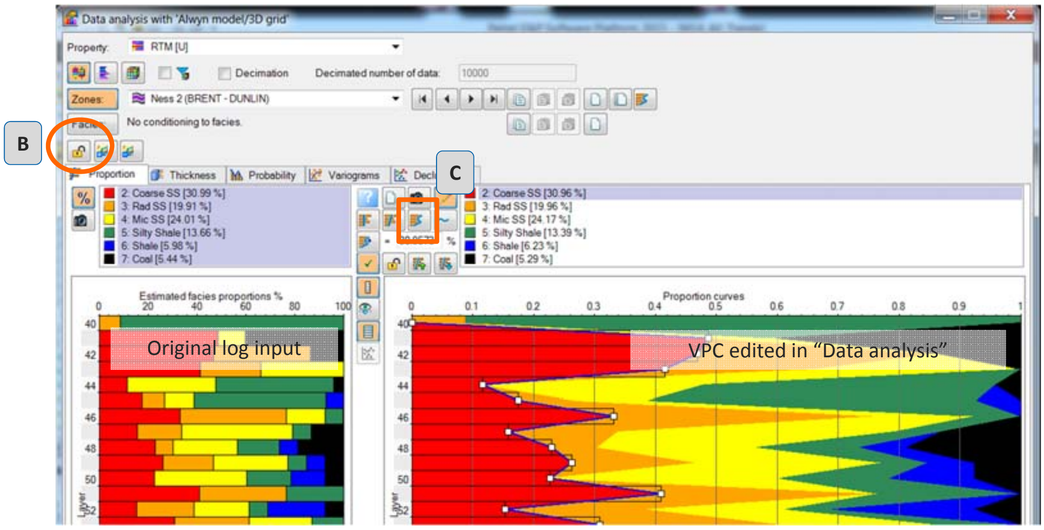
Vertical Proportion Curves (VPC)

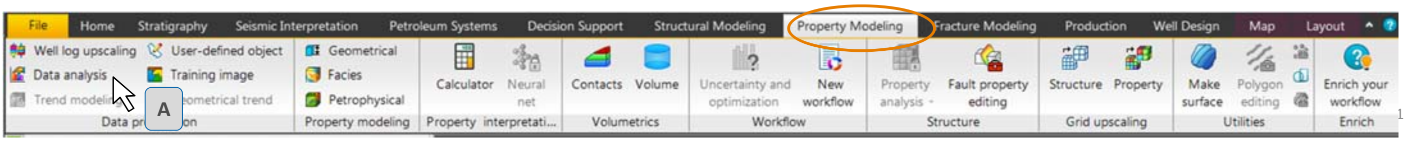
- **The VPC is a geostatistical tool** used to calculate rock type proportions based on well information in order to identify a trend.



Data analysis: create a VPC

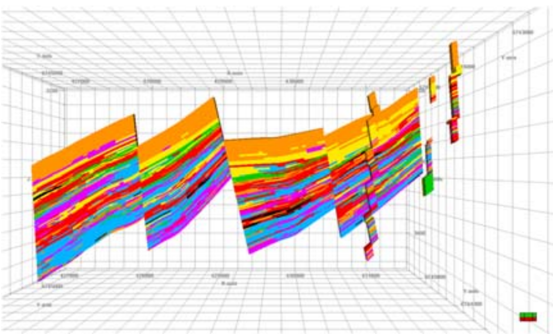
- **“Processes” → “Data analysis” → “Property modeling”**
  - Property Modeling Ribbon → “Data analysis” (A)
  - To visualize histograms with upscaling results: unlock (B)
  - Edit VPC (Vertical Proportion Curves) (C) for each rock type and each zone by selecting “fit curves to histogram” icon
  - “Apply” to validate VPC and select same settings for other zones

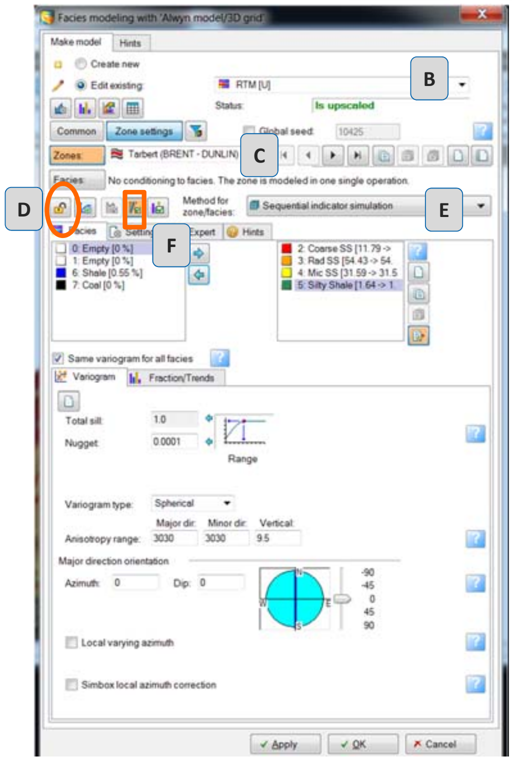


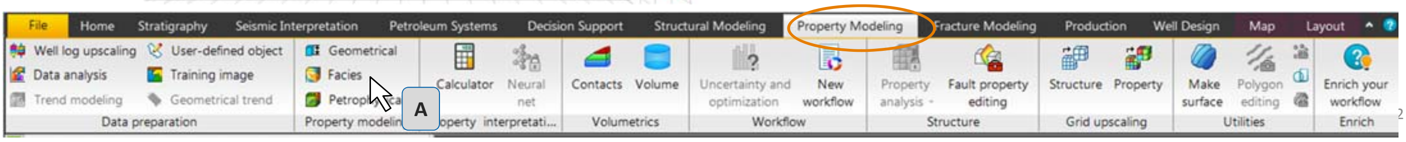


Facies modeling - Settings

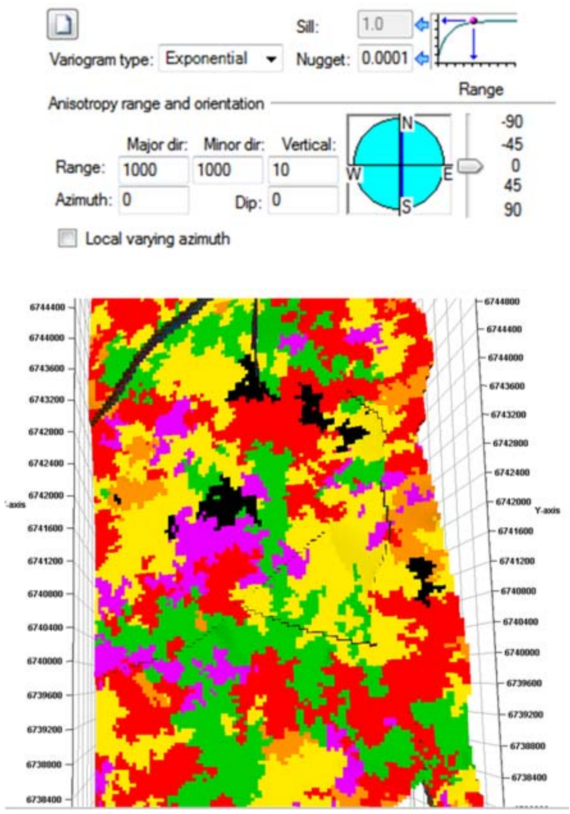
- Sequential Indicator simulation method for all zones
  - Select “Facies” in the Property Modeling ribbon (A)
  - Select the desired property upscaled as “Existing property” (B)
  - Select Tarbert (C), unlock settings (D) and select the algorithm
  - “Sequential Indicator Simulation" for all zones (E)
  - For each zone, select the facies to be populated according to the data analysis results
  - Click on the 4th icon (“Adjust to VPC result”) to load VPC result (F)
  - Use the same settings for the other zones

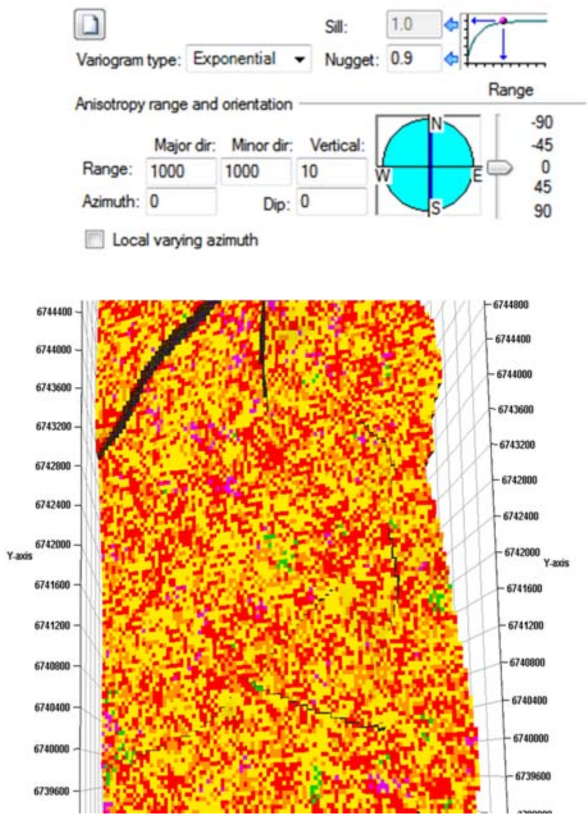




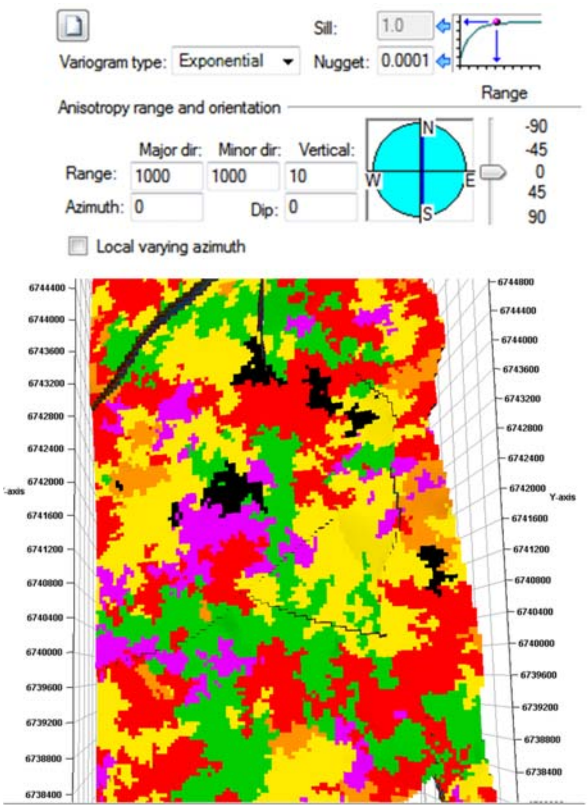


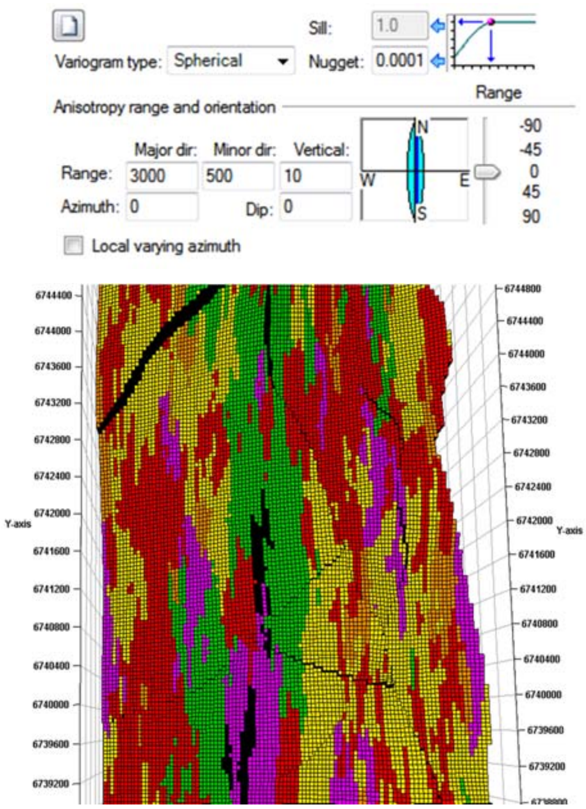
Variogram: nugget effect



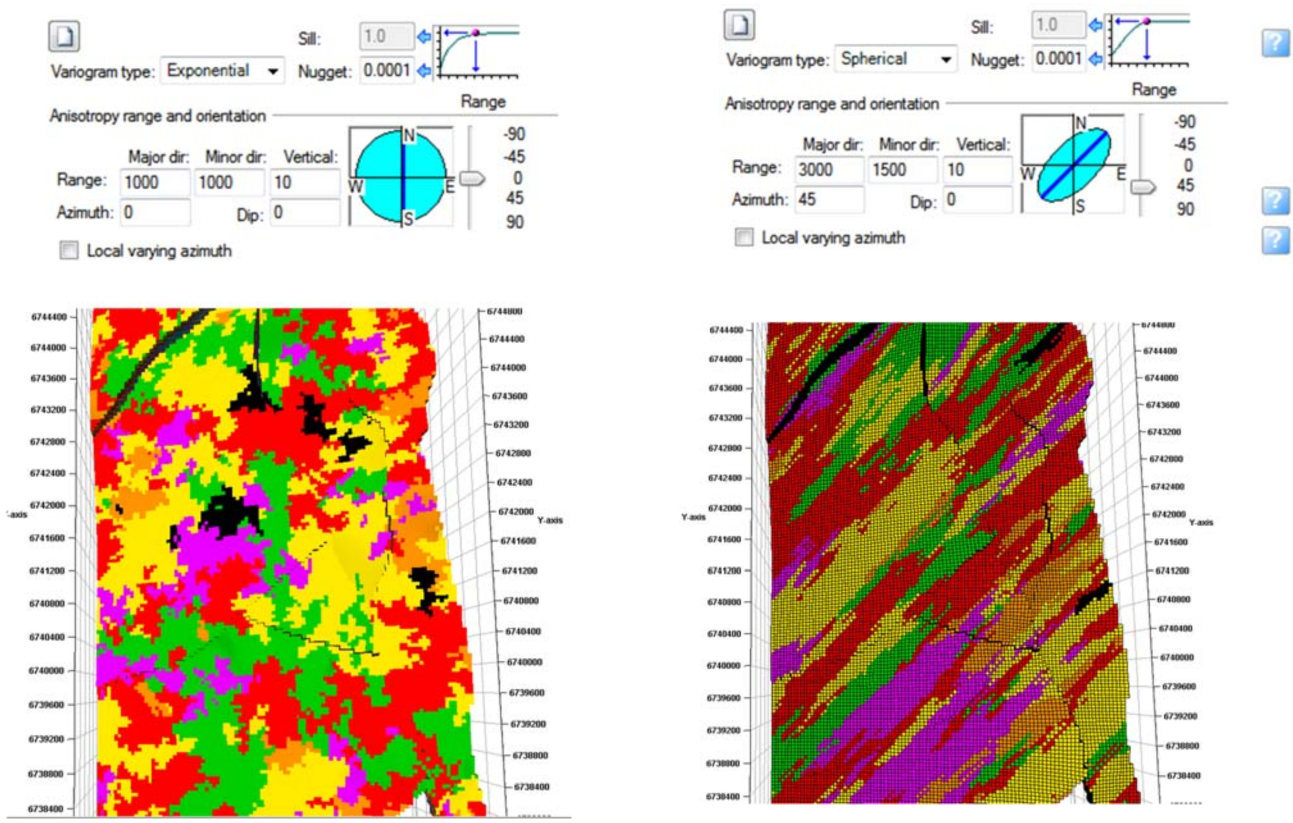


Variogram: Isotropic vs Oriented



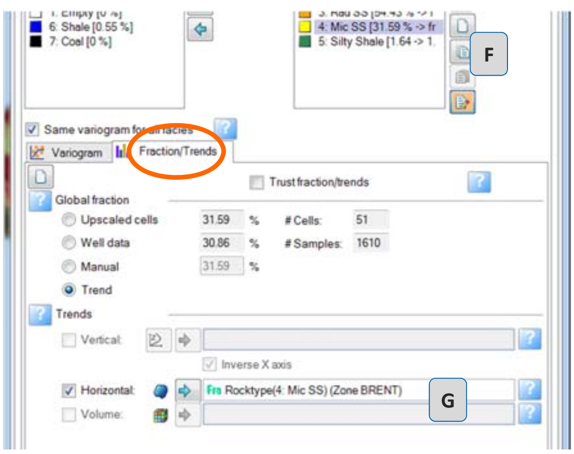


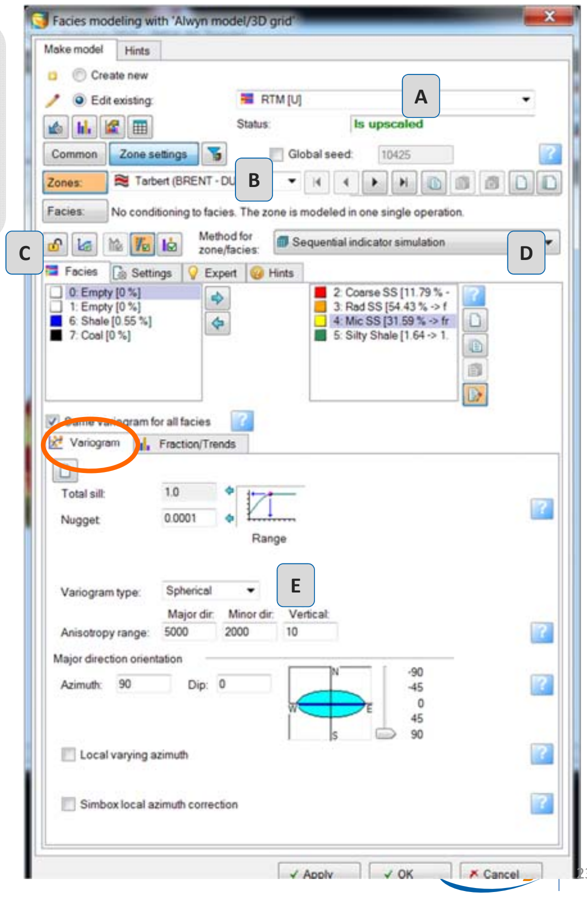
Variogram: Azimuth



Tarbert facies modeling

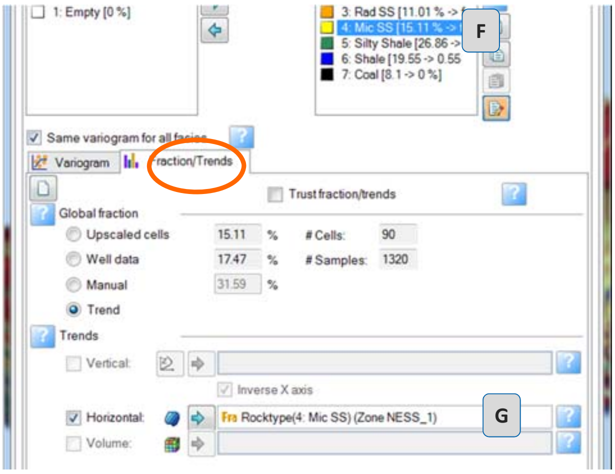
- **Sequential indicator simulation for Tarbert zone**
  - Select your upscaled facies property as “Existing property”(A)
  - Select Tarbert (B), unlock settings (C) and select “Sequential indicator simulation (D)
  - Modify the variogram parameters (E)
  - For each facies (F) select the fraction trend (G)

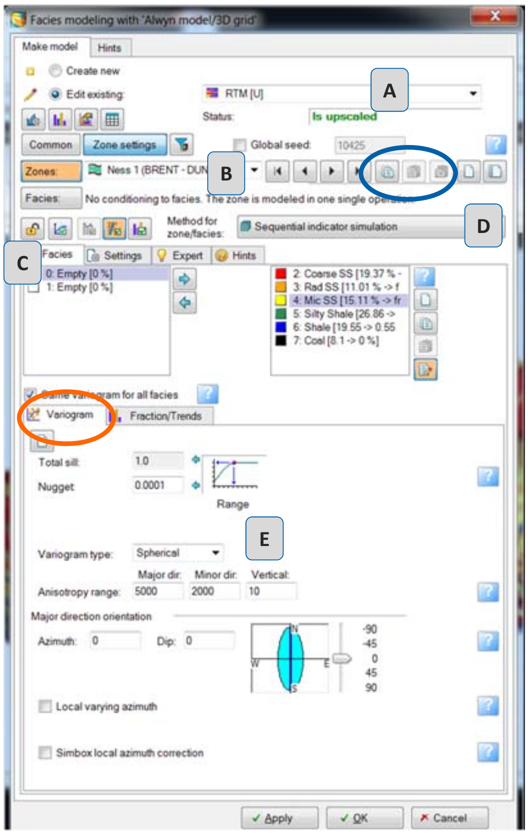




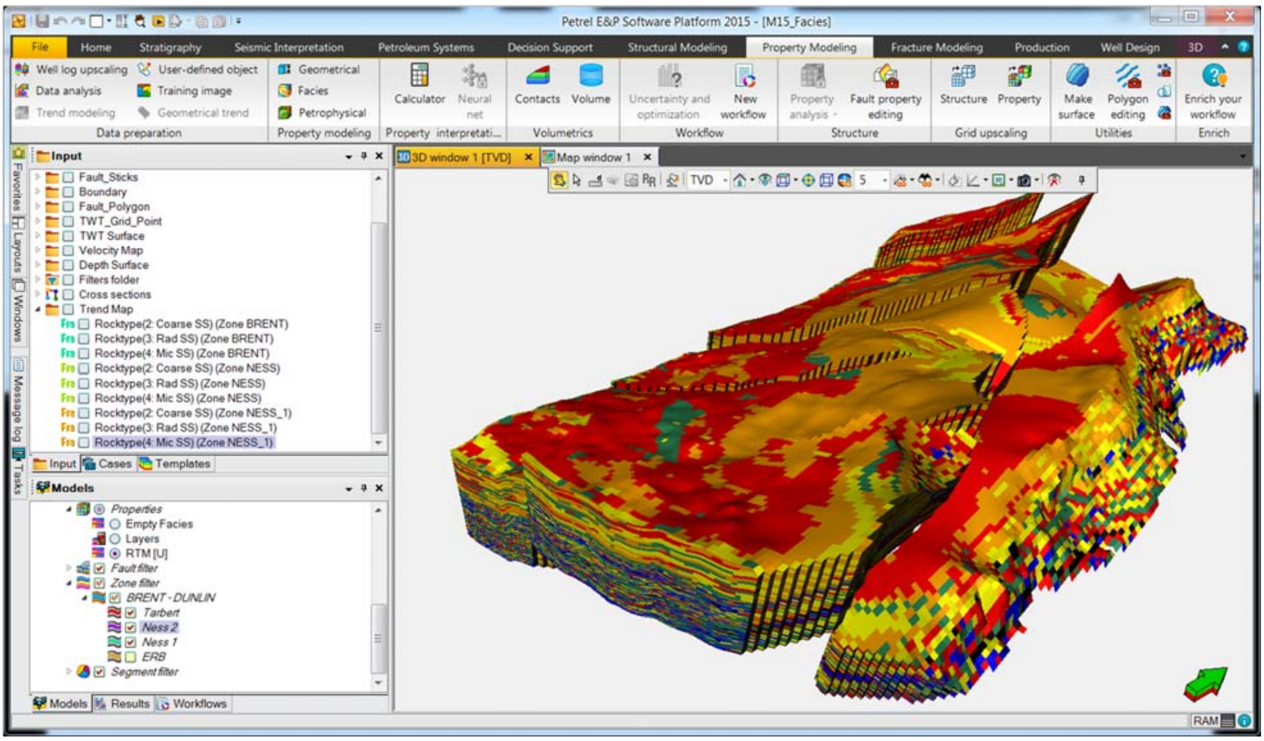
Ness 1 / Ness 2 facies modeling

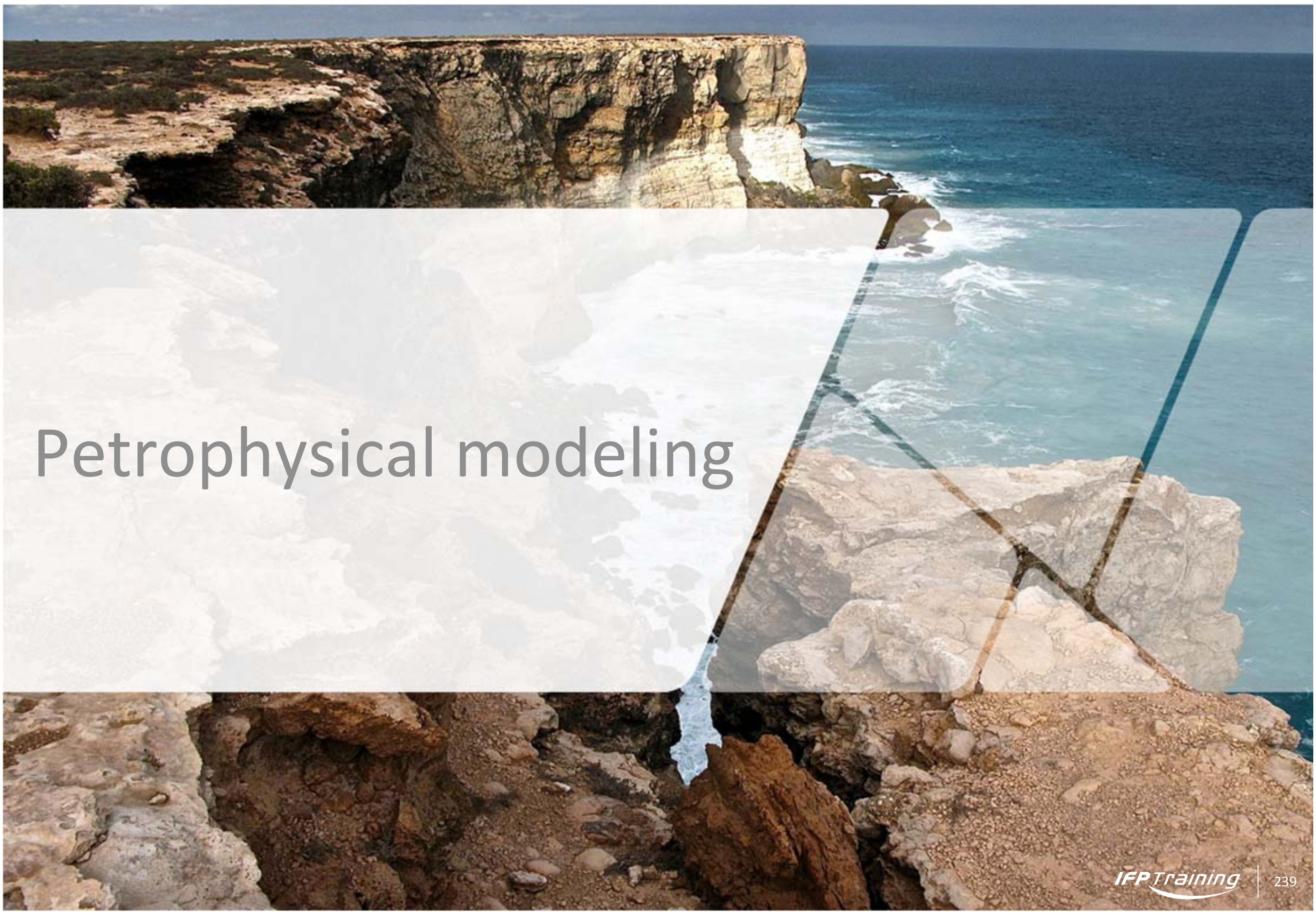
- **Sequential indicator simulation for Ness 1 / Ness 2 zones**
  - Select your upscaled facies property as “Existing property” (A)
  - Select Ness 1 (B), unlock settings (C) and select “Sequential indicator simulation (D)
  - Adjust variogram parameters (E)
  - For each facies (F) select fraction trend (G)
  - For Ness 2 copy Ness 1 parameters and paste on to Ness 1 zone (blue circle), adjust trends maps.





M15_Facies



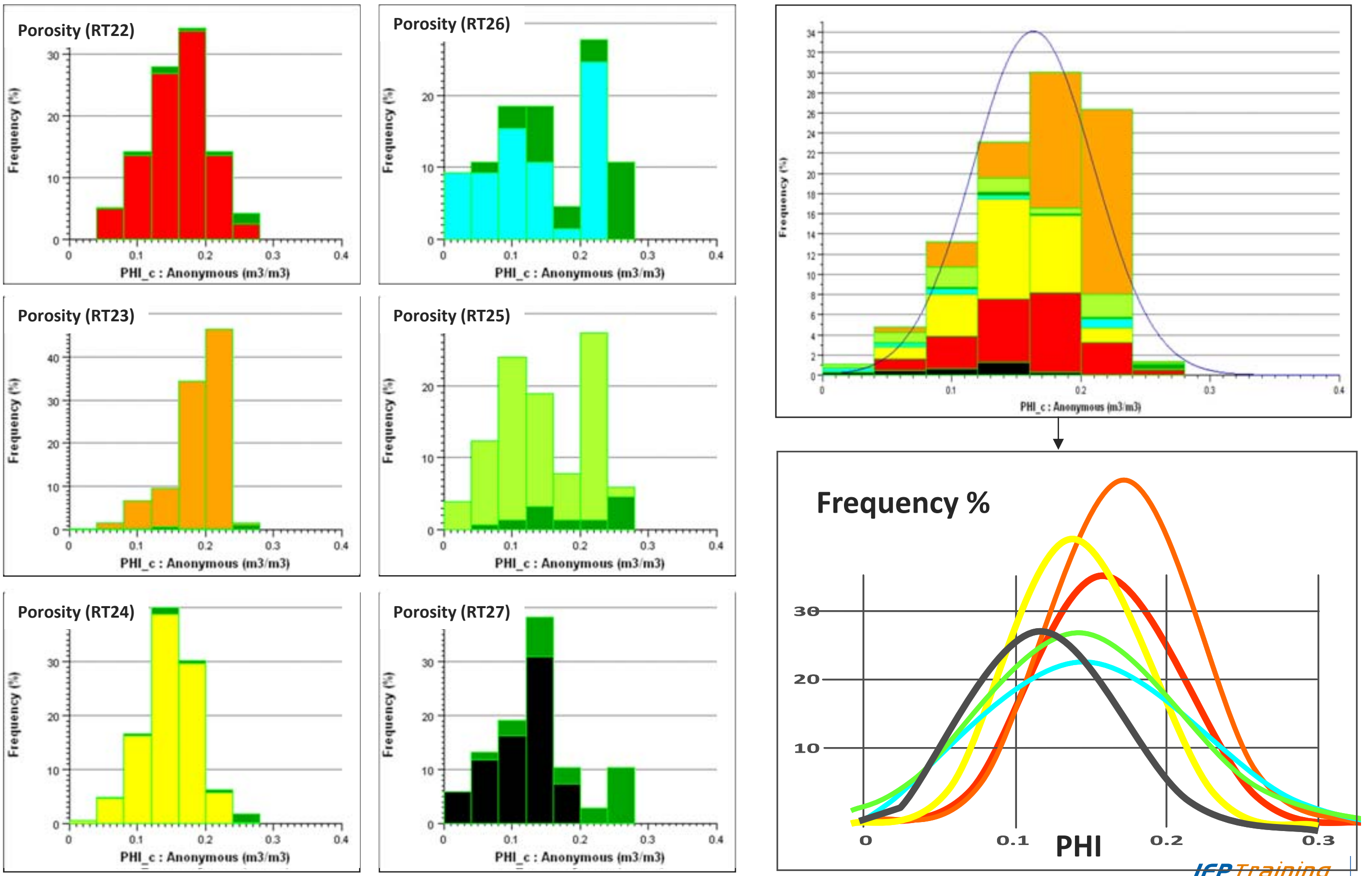


Petrophysical modeling

Petrophysical characterization

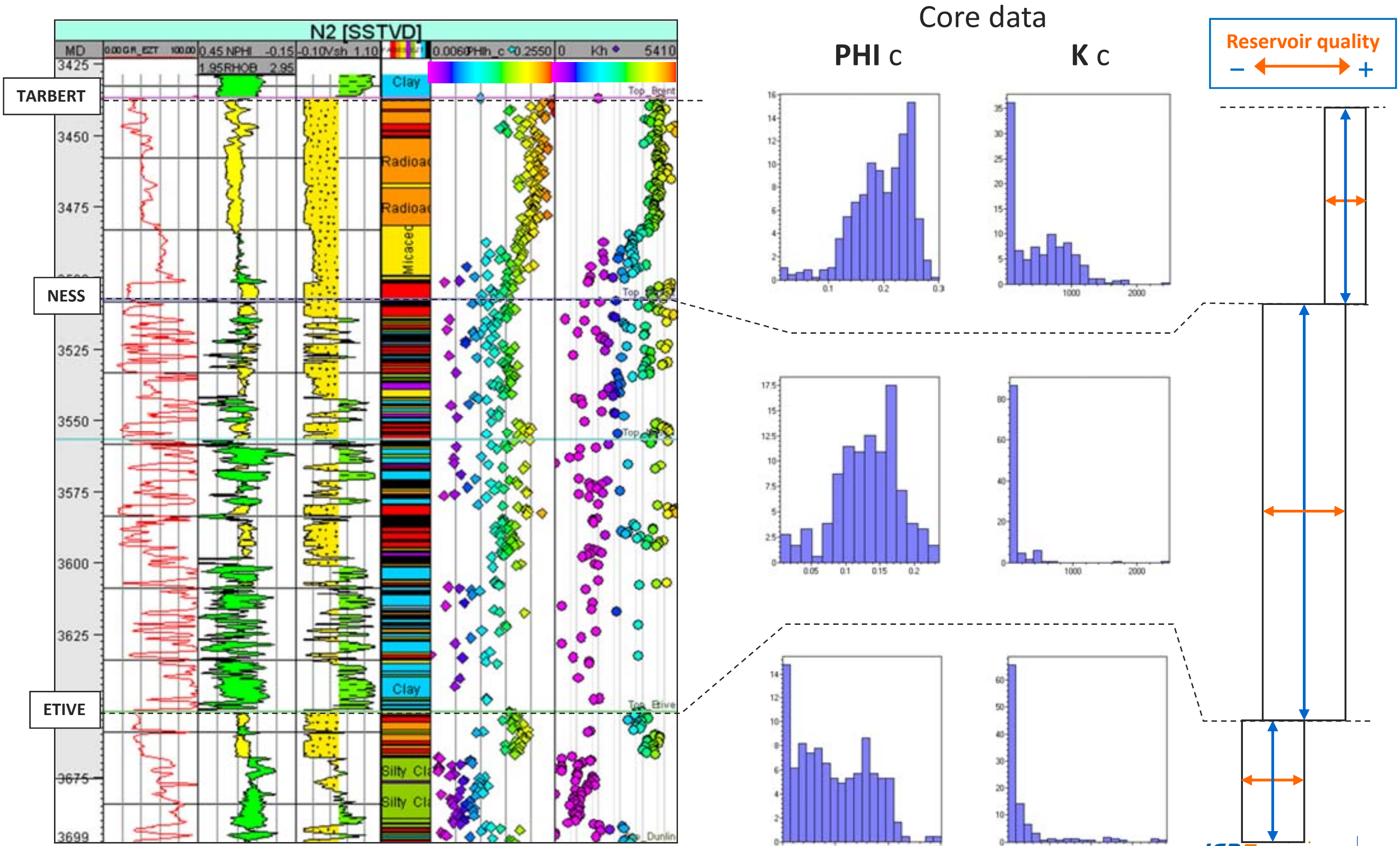
Hands-on

Porosity distribution functions

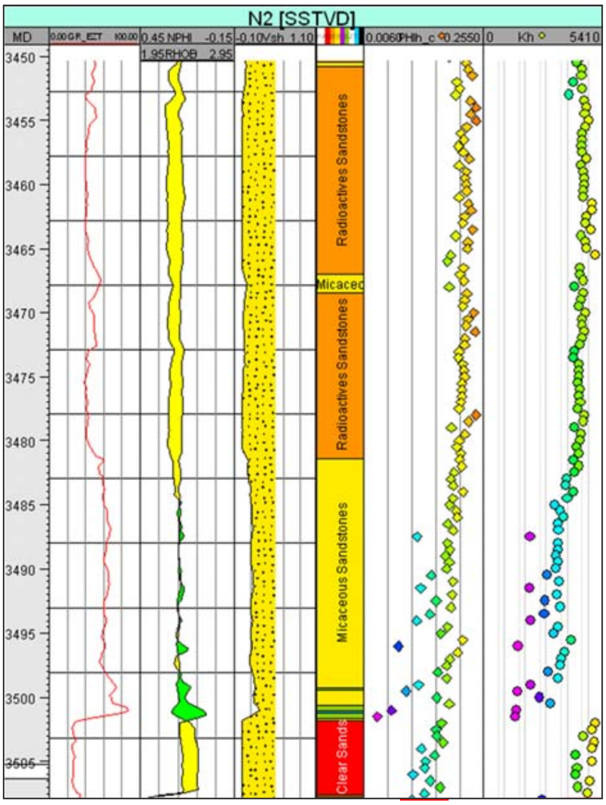


Exported from EasyTrace

Petrophysical parameters & reservoir potential

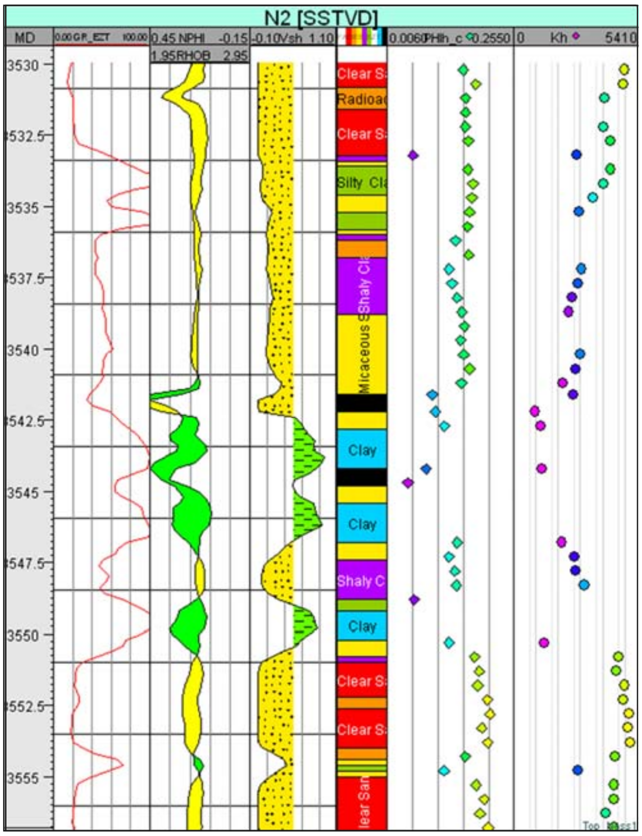


Reservoir properties for high potential facies



- **F3: Radioactive sandstone**
  - Consistent value distribution
  - Best porosity
  - Medium permeability
  - → **High reservoir potential**
- **F4: Micaceous sandstone**
  - Highly scattered values
  - Medium porosity
  - Lowest permeability
  - → **Low reservoir potential**
- **F2: Clean sandstone**
  - Limited value scattering
  - Lowest porosity
  - Best permeability
  - → **High reservoir potential**

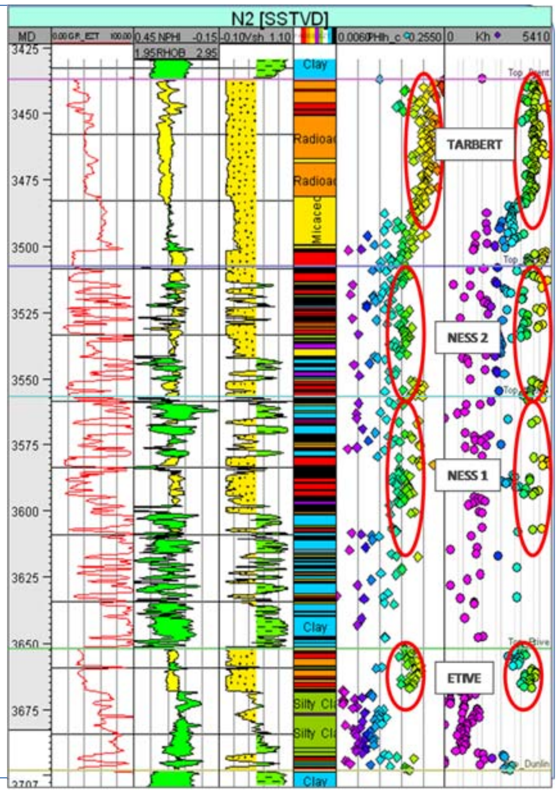
Reservoir properties for low potential facies



- **F5 & F6: Silty/Shaly facies**
  - Limited value scattering
  - Lower porosity than high potential facies
  - Lower permeability than high potential facies
  - → **No reservoir potential**
- **F8 & F9: Shale & Coal**
  - Limited value scattering
  - Bad porosity
  - Bad permeability
  - → **No reservoir potential**

Petrophysical characterization – Key points

- **Petrophysical parameter analysis helps to establish a more accurate hierarchy between each facies relative potential:**
  - High reservoir potential facies: (F3) & (F2)
  - Low reservoir potential facies: (F4), (F5) & (F6)
  - No reservoir potential facies: (F8) & (F9)
- **It also helps ranking reservoir zone quality:**
  - Tarbert is the best reservoir zone
  - Ness is a good reservoir zone, with a higher potential for Ness 2 than for Ness 1
  - Etive is a low potential reservoir zone, except for a few meters at the top



Petrophysical parameter modeling

Hands-on

If any problem: Open project "M16_Facies"

Porosity modeling

M15_Facies

Petrophysical result summary table – From EasyTrace

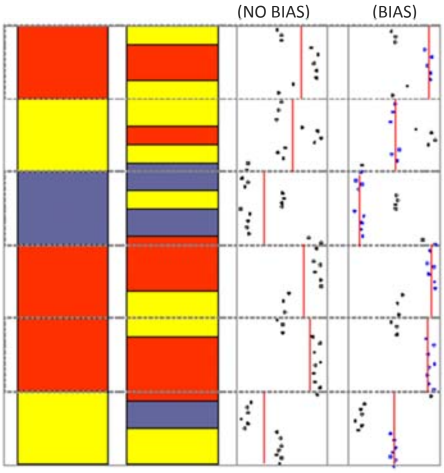
	Rock Types	RT2	RT3	RT4	RT5	RT6	RT7
	LithoFacies	Clean SS	Radioactive SS	Micaceous SS	Silty shale	Shale	Coal
	ElectroFacies	EF22	EF23	EF24	EF25	EF26	EF27
PetroFacies	PHI min	0.11	0.127	0.021	0.02	Cste = 0,001	Cste = 0,001
	PHI max	0.22	0.248	0.214	0.14		
	PHI mean	0.16	0.194	0.141	0.07		
	PHI Std. Dev.	2.63	3.01	4.36	3.4		
	(K) = 10(a*PHI+b)	a = 0.087 b = 1.088	a = 0.171 b = -1.07	a = 0.178 b = -1.67	a = 0.132 b = -1.89	Cste = 0,001	Cste = 0,001

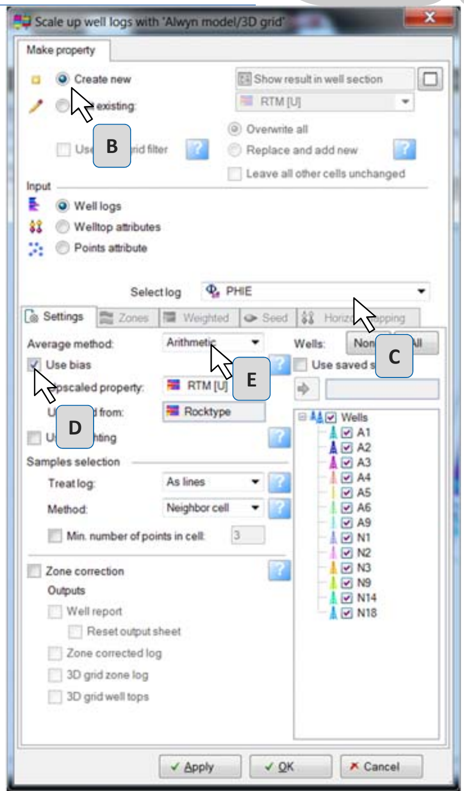
y = f(x) = ax + b

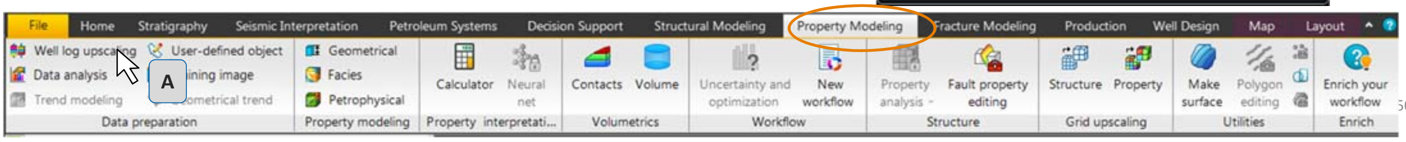
Porosity log (NPHIE) upscaling

- Property modeling ribbon → “Well log upscaling” (A)
- Create new (B)
- Choose upscaled log in the “Select logs” window PHIE (C)
- Select “Facies” log as “Bias (D)” to keep the facies trend.
- Select “Arithmetic” algorithm (E)

Mean (NO BIAS) Mode (BIAS)

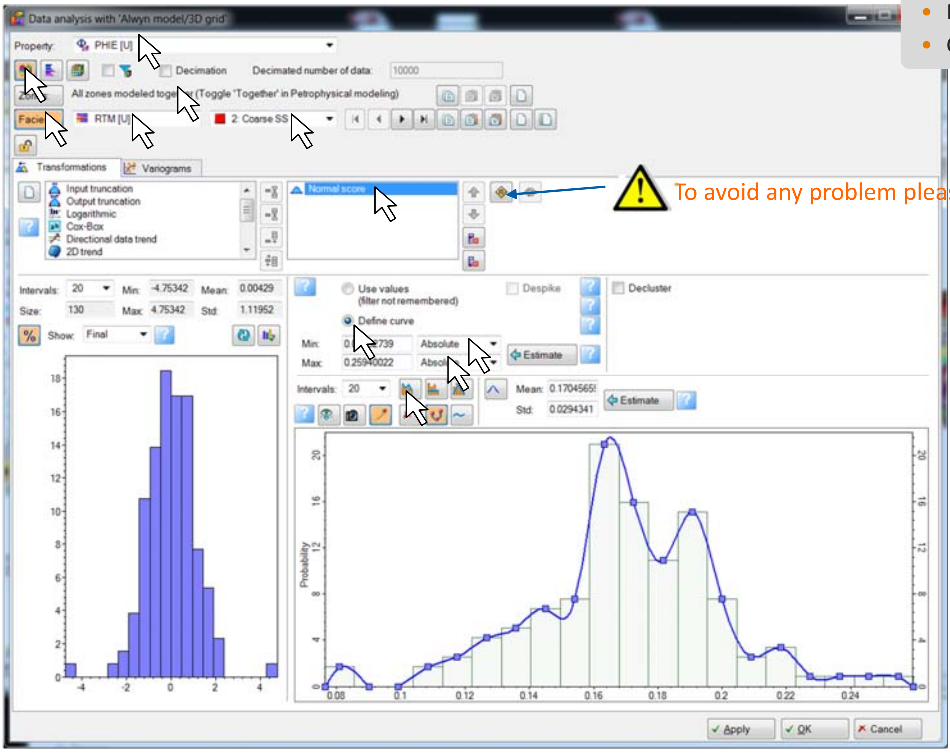


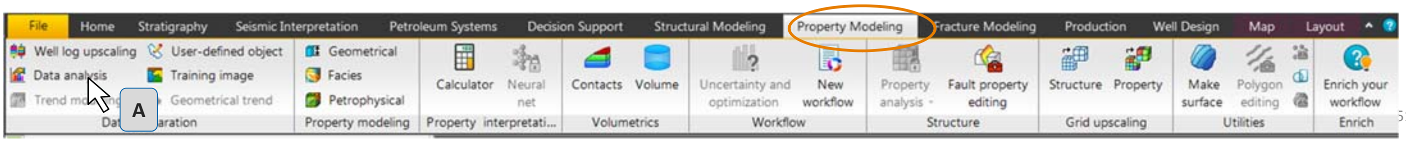




Porosity data analysis – Gaussian law for Clean SS

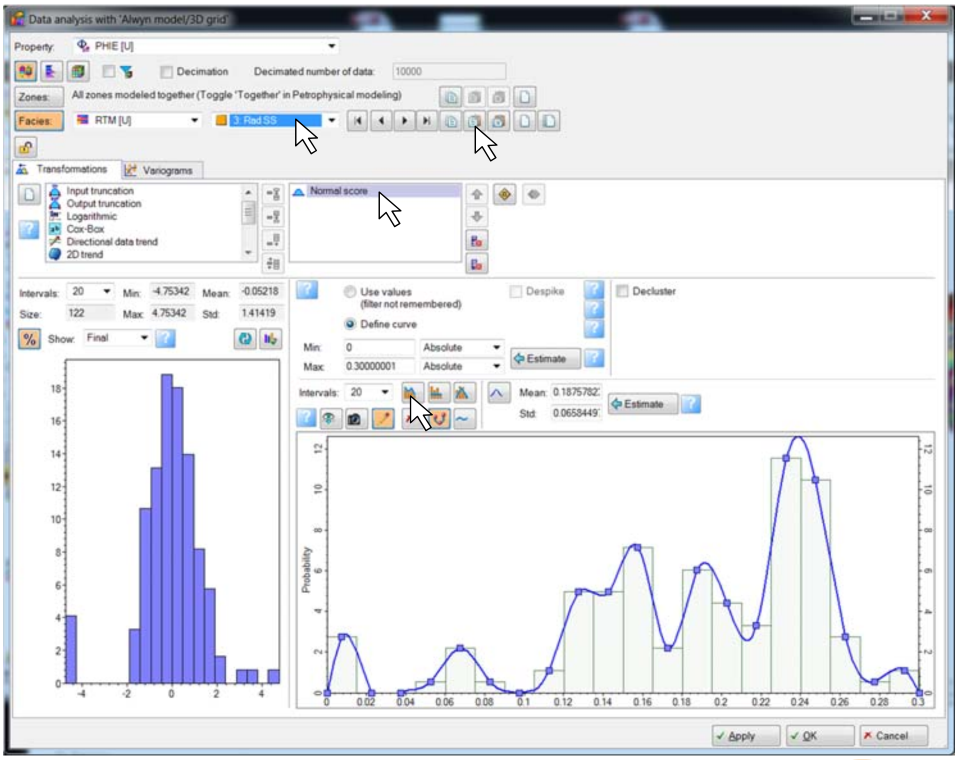
- Property modeling ribbon "Data analysis" (A)
- Change parameter as following and "Apply"

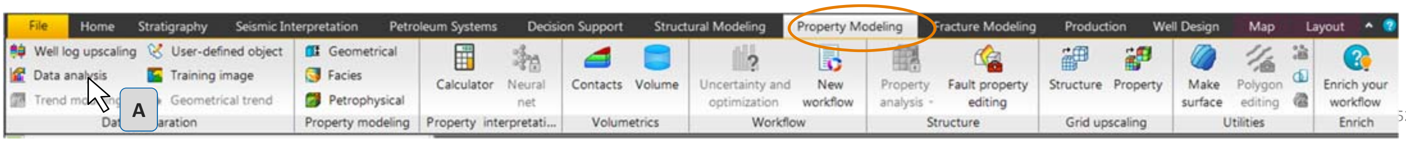




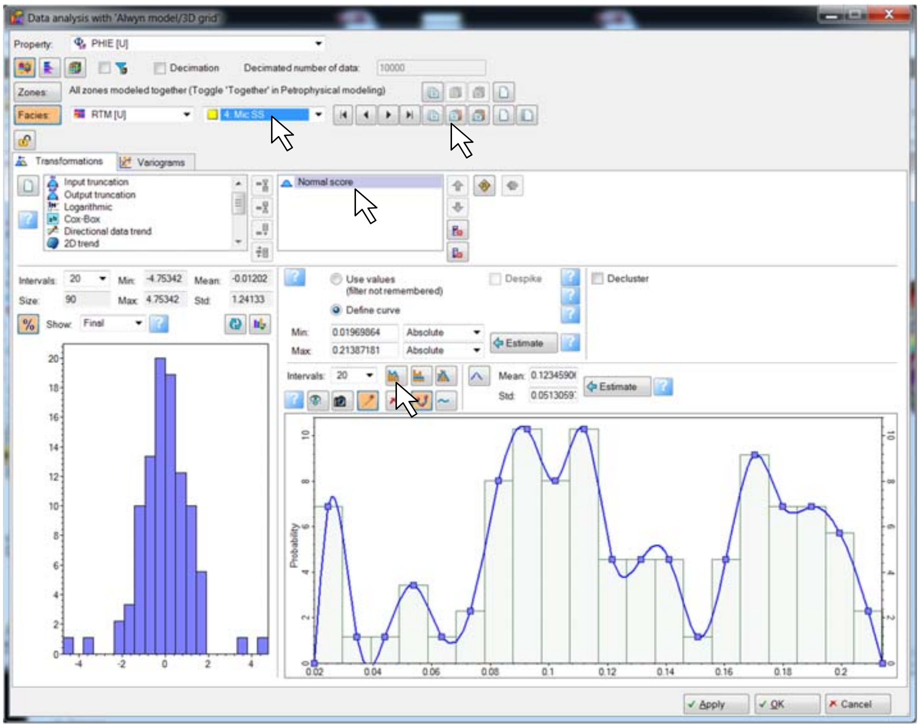
Porosity data analysis – Gaussian law for Rad SS

- Use copy paste and adjust law
- "Apply"



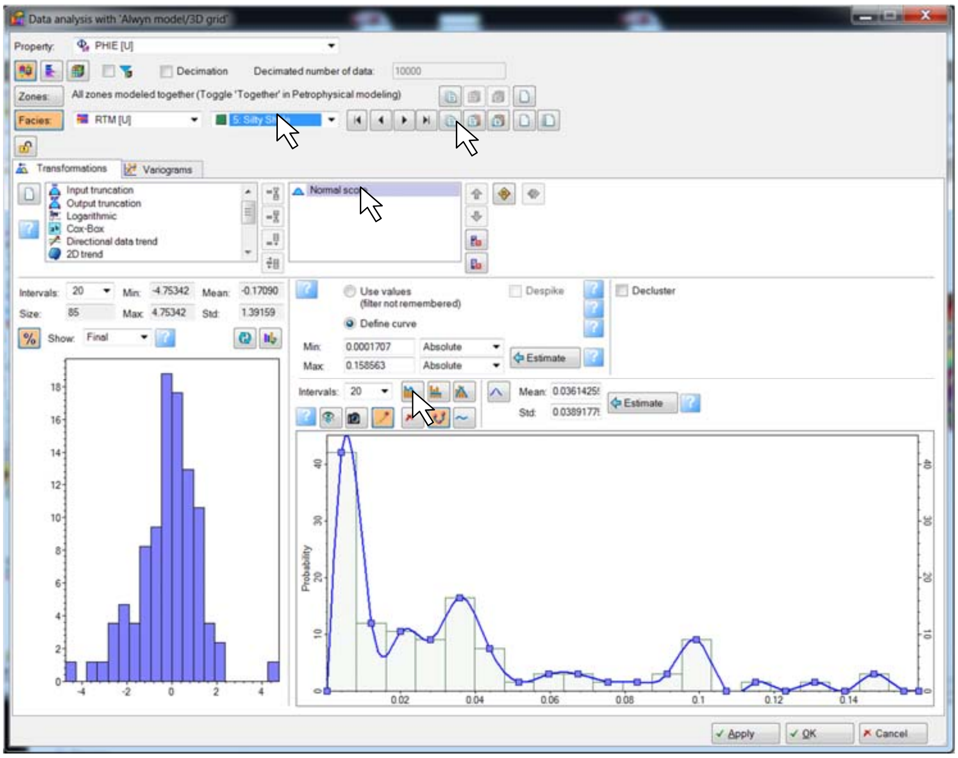


Porosity data analysis – Gaussian law for Mic SS



- Use copy paste and adjust law
- “Apply”

Porosity data analysis – Gaussian law for Silty Shale

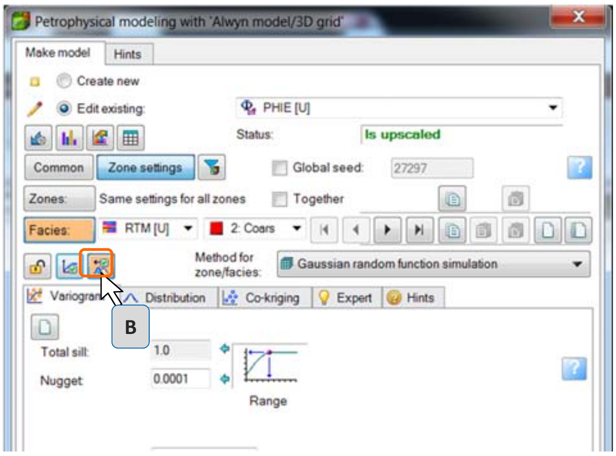


- Use copy paste and adjust law
- “Apply”

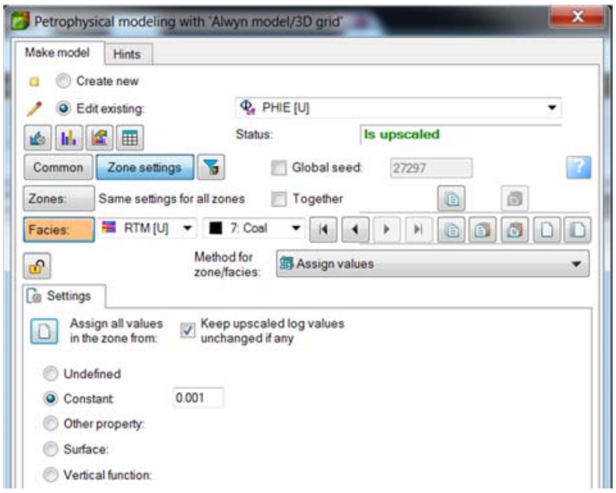
Porosity modeling

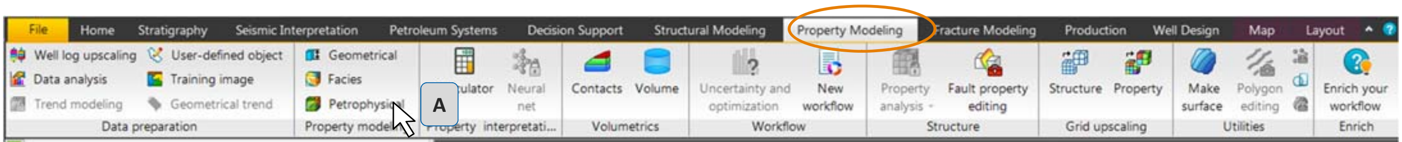
- Property modeling ribbon “Well log upscaling” (A)
- Fix the same filters (Facies, Zones) than in “Data analysis”
- Select “Gaussian Random Simulation Function” in “Method” except for Shale/coal where “Assign value” is recommended.
- Select the icon “Use transformations from Data analysis”(B) except for Shale/coal (value is fixed at 0.001).

Use the Gaussian random function simulation for Clean SS, Radioactive SS, Micaceous SS and Silty Shale

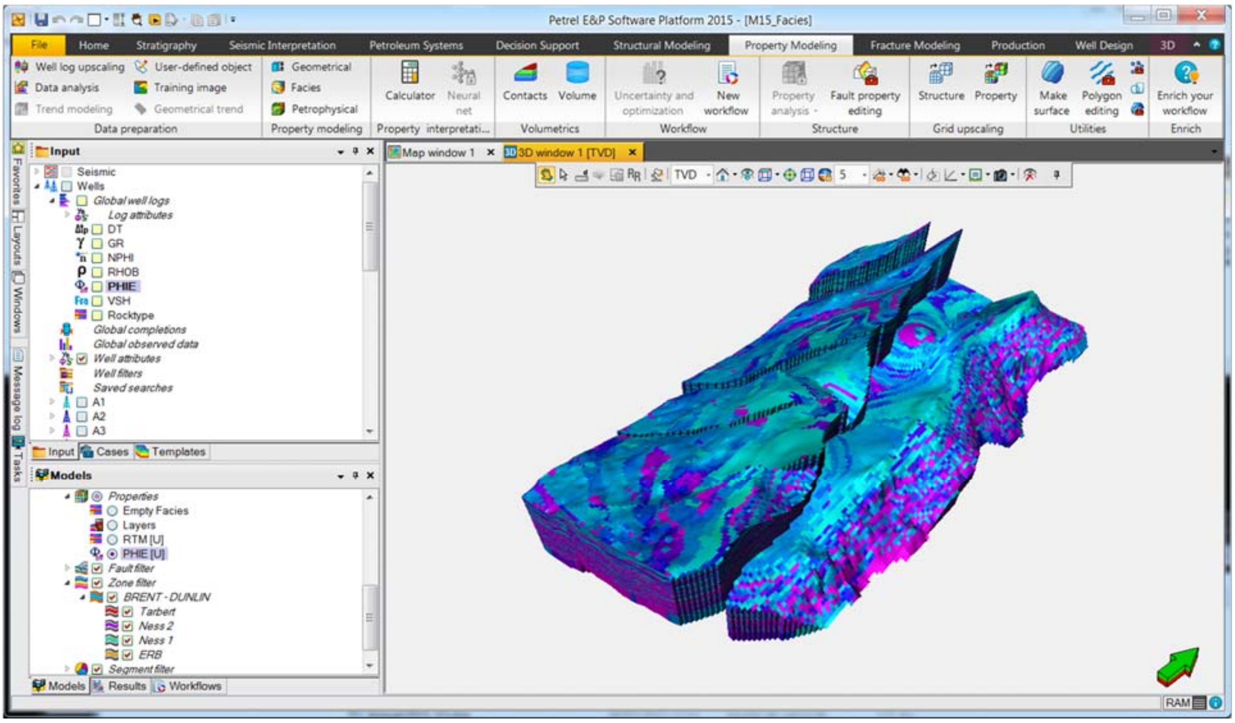


Use assign value for shale and Coal



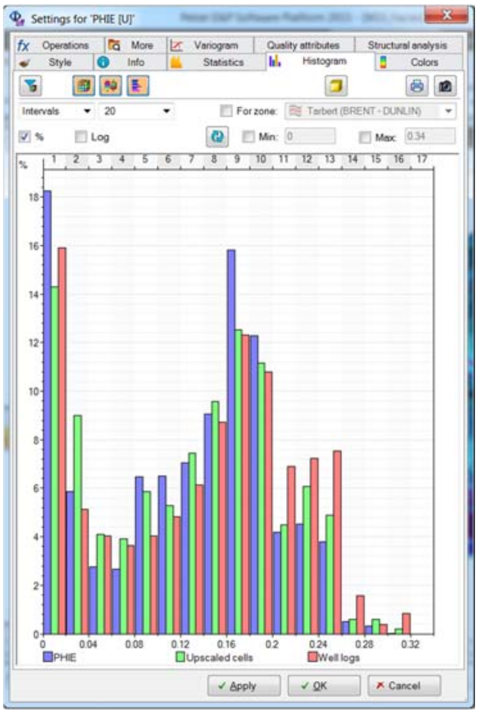


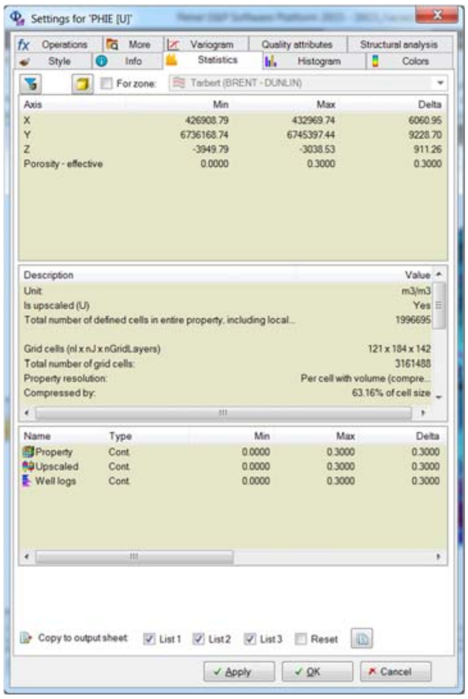
Porosity modeling



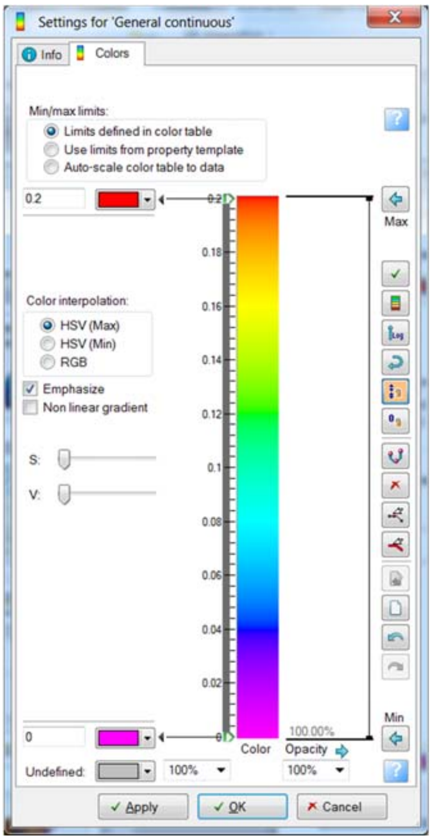
Porosity modeling

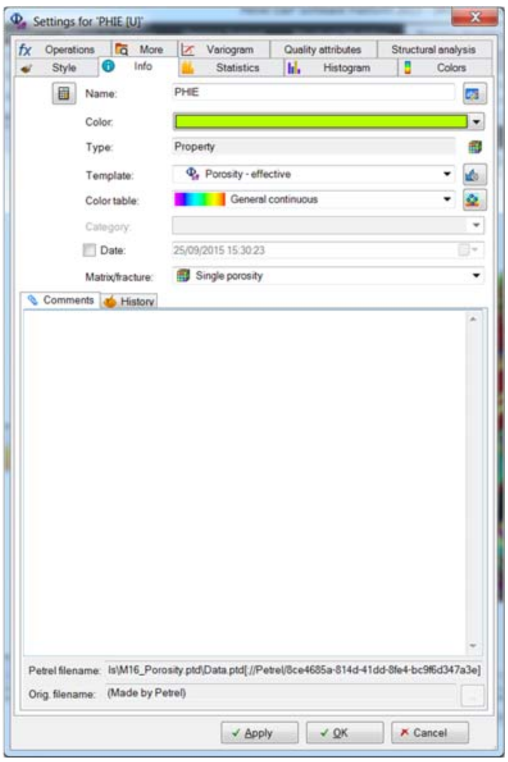
- Select "PHIE" property
- Settings and histogram
- Settings Statistics



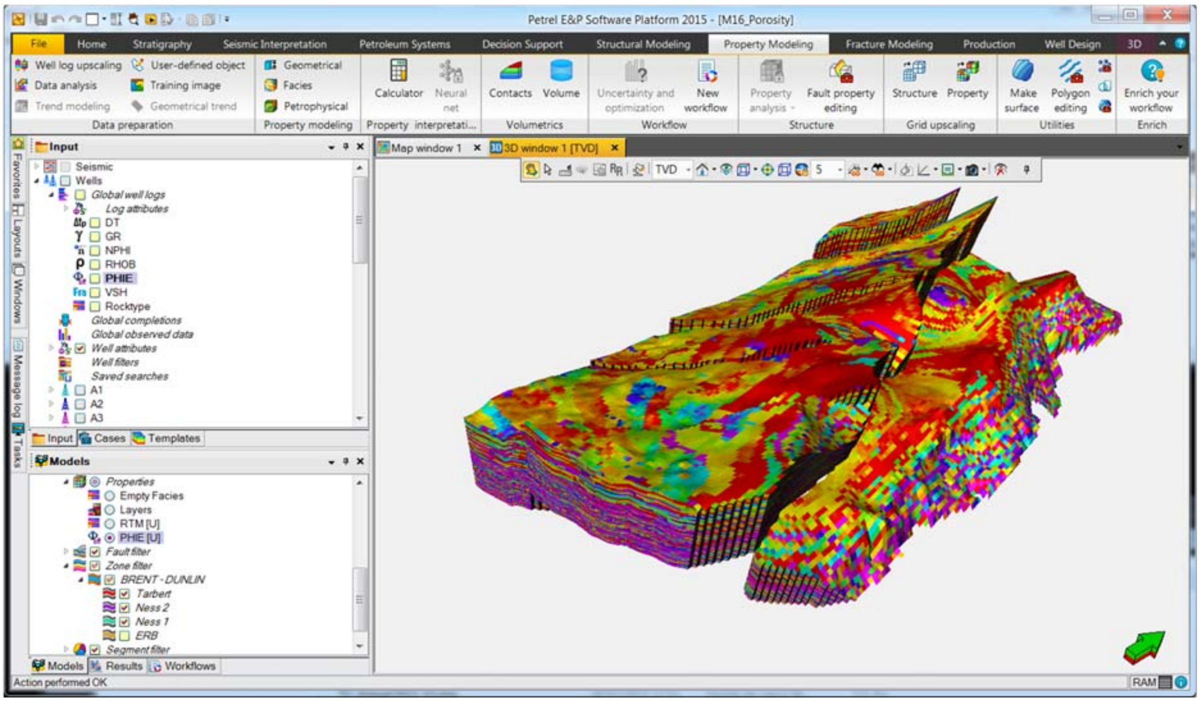


Porosity modeling – Adjust color scale



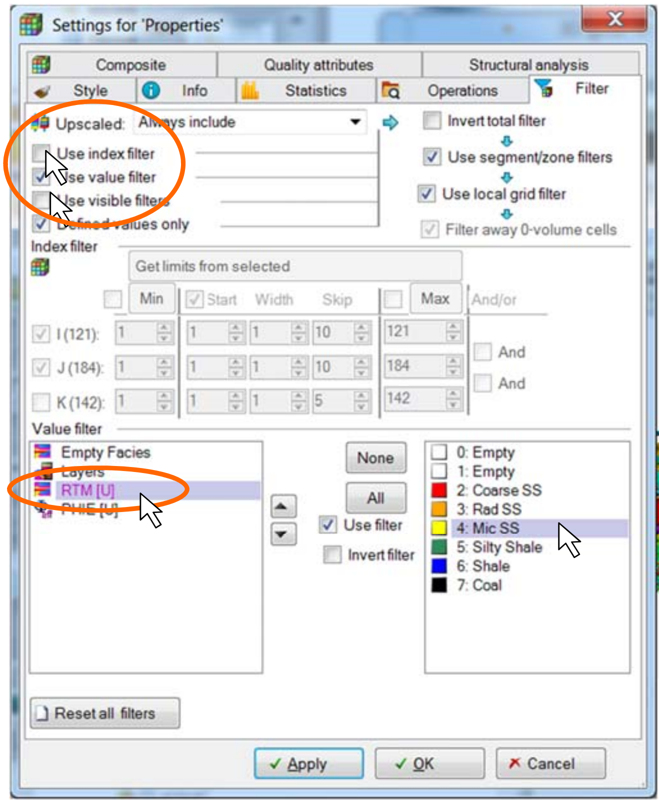


M16_Porosity

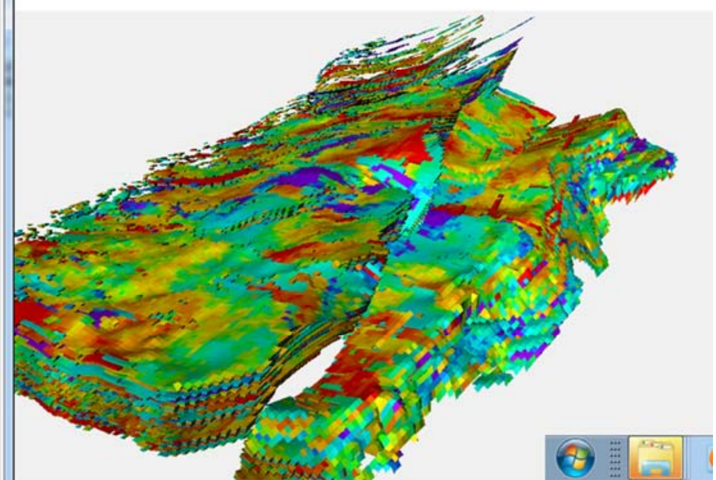


Use cut-off filter for QC

- 3D grid → properties (right click)
- To make filter on a 3D grid and highlight a specific parameters combination only



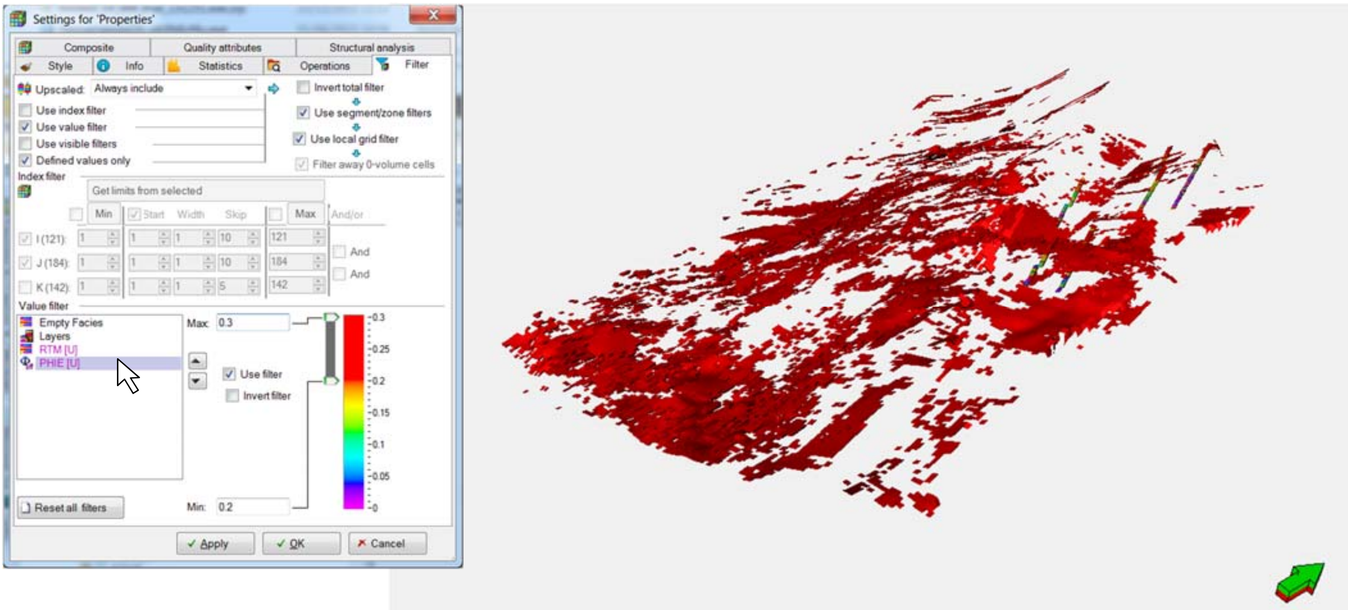
To see only cell with "Micaceous SS"



It is possible to combine filters:
i.e. Micaceous SS with porosity > 20…

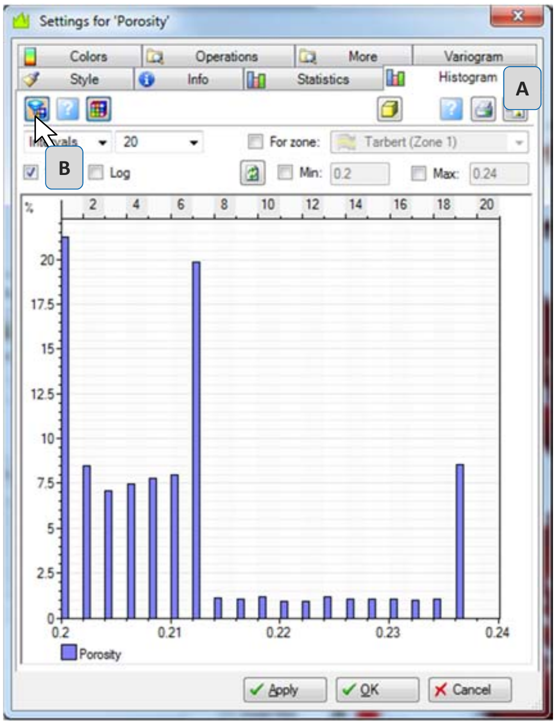
Use cut-off filter for QC

- It is possible to combine filters: i.e. Micaceous SS with porosity > 20…



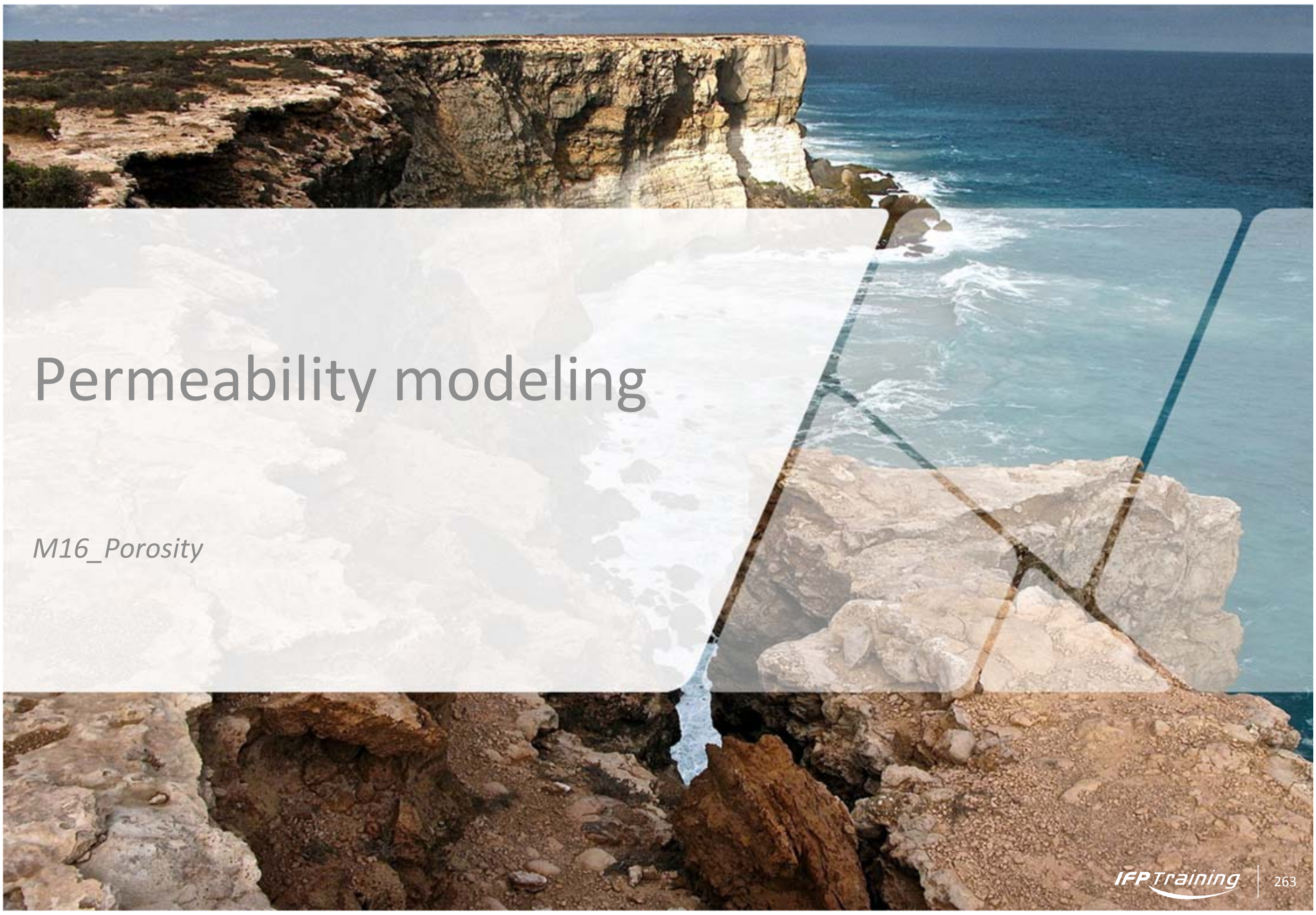
Use cut-off filter for QC

- To visualize a histogram on filtered data:
- Select a property – Right click and “Settings”
- Select Histogram (A) and click on filter icon (B)



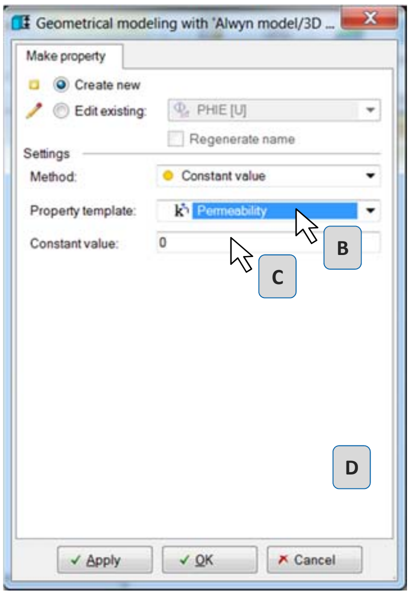
Permeability modeling

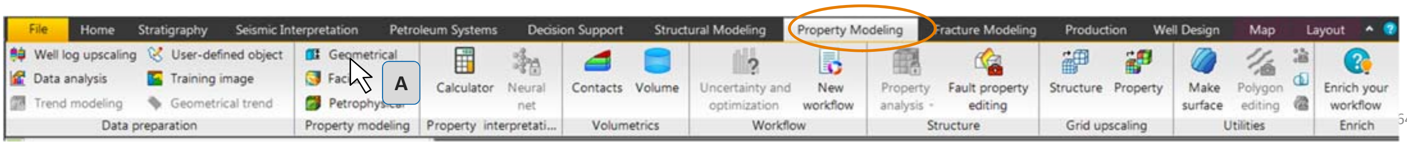
M16_Porosity



Create Porosity and Permeability properties

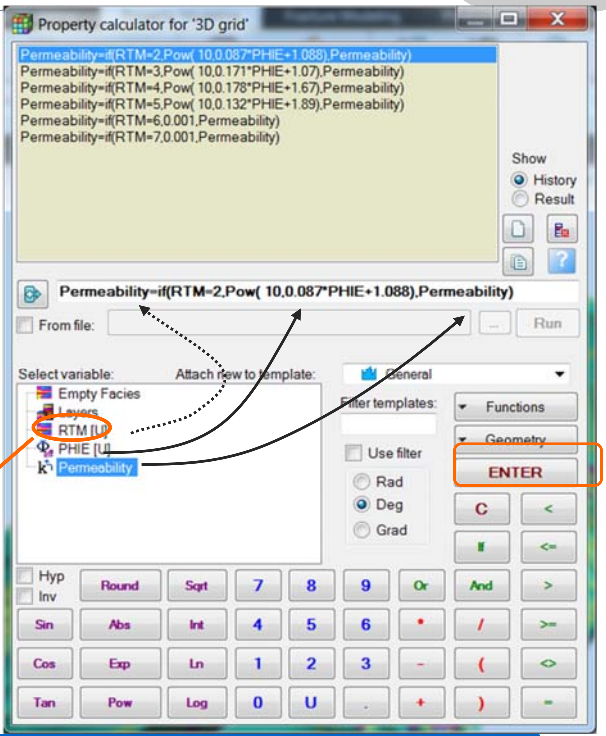
- **Create a permeability property**
  - Property modeling Ribbon → Geometrical (A)
  - Property template choose: Permeability (B)
  - Type in "0" as constant value (C)





Permeability modeling with a K/ϕ distribution function

- **Build a permeability model based on Rock-type (RTM) and K/ϕ distribution**
  - On Models tab select Permeability property, right click and select "Calculator"
  - For each Rocktype (RTM), enter K/ϕ law in formula with "If" function and Enter
  - Repeat the operation with other Rock-types



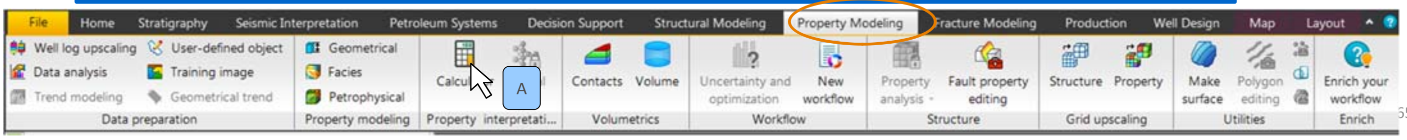
K/Phi transform:

RT2: Log(K): 0.087*Porosity+1.088
RT3: Log(K): 0.171*Porosity+1.07
RT4: Log(K): 0.178*Porosity+1.67
RT5: Log(K): 0.132*Porosity+1.89
RT6: K=0.001
RT7: K=0.001

RTM = Rock Type Model

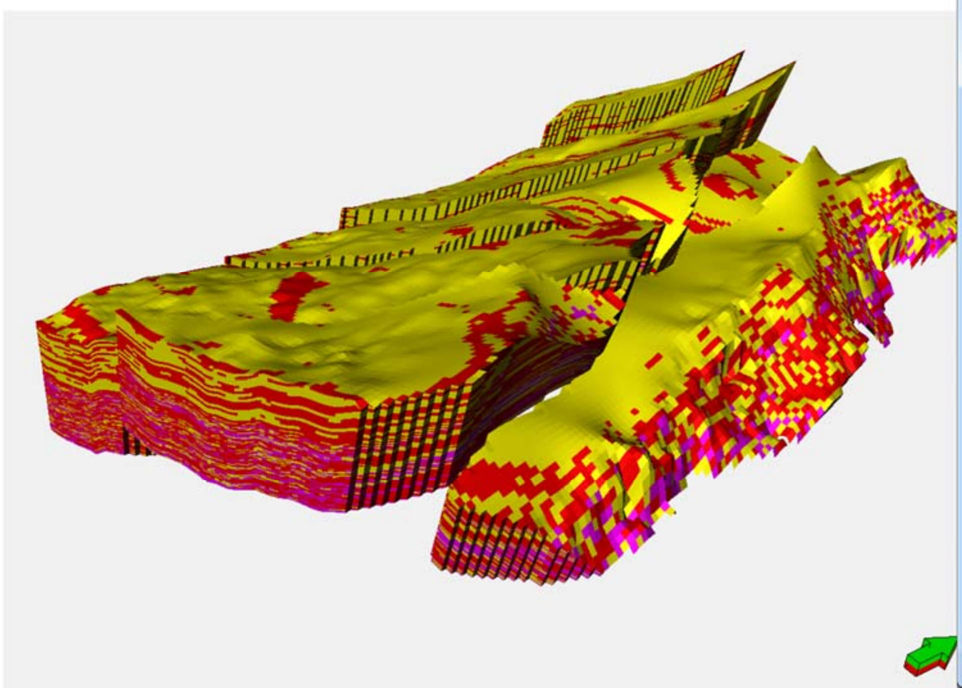
Formula to use:

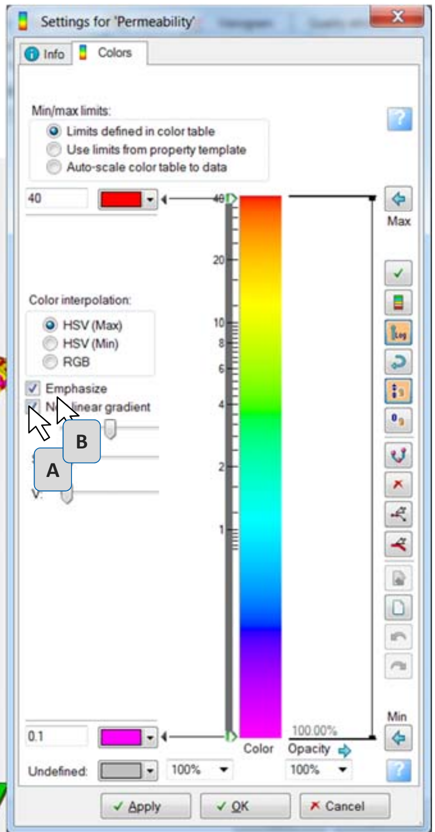
Permeability = if (RTM = 2, Pow (10,0.087*Porosity + 1.088), Permeability)



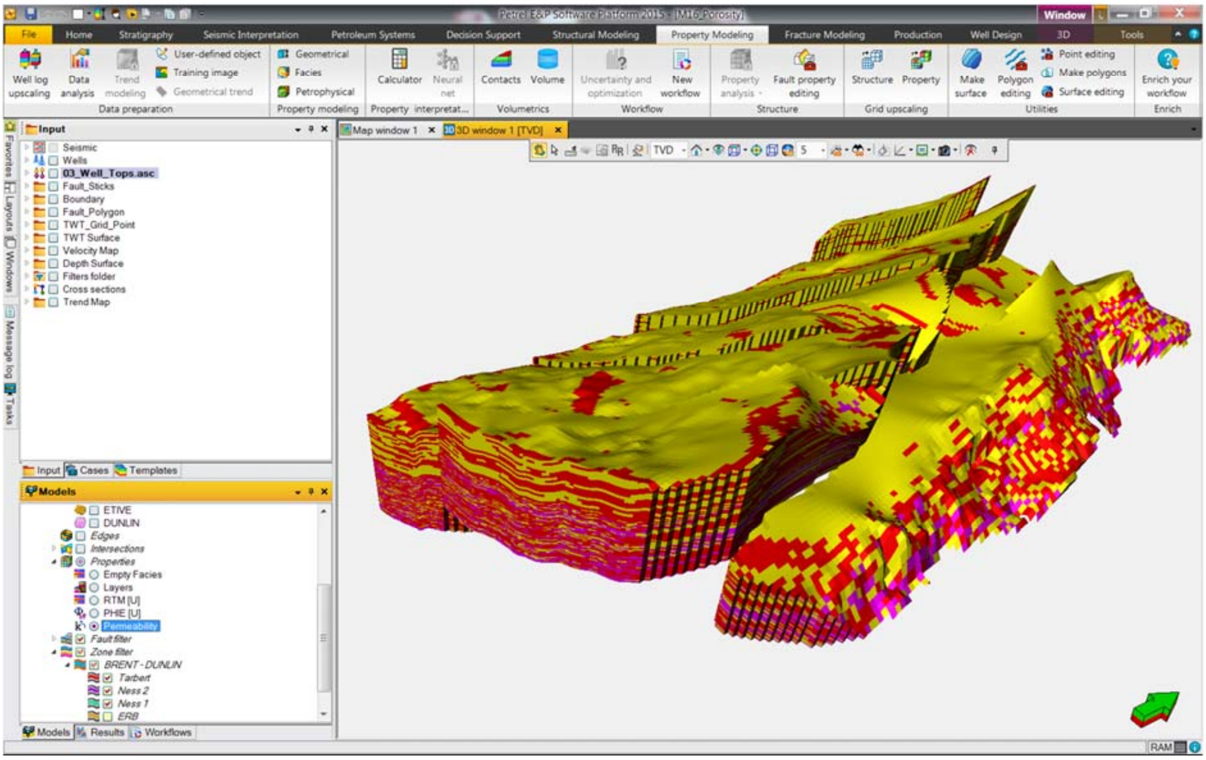
Permeability modeling with a K/ϕ distribution function

- Choose a non linear gradient (A)
- Move cursor to adjust color scale (B)
- Max = 40

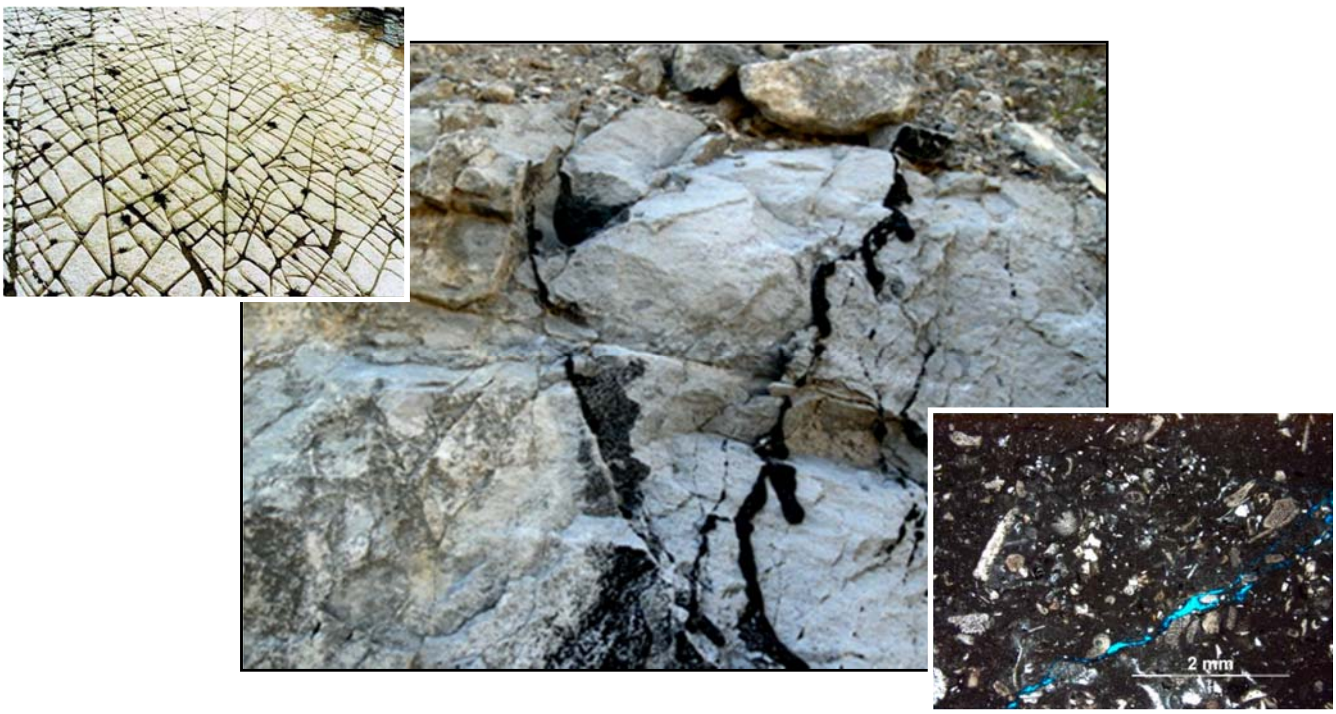




M17_Permeability

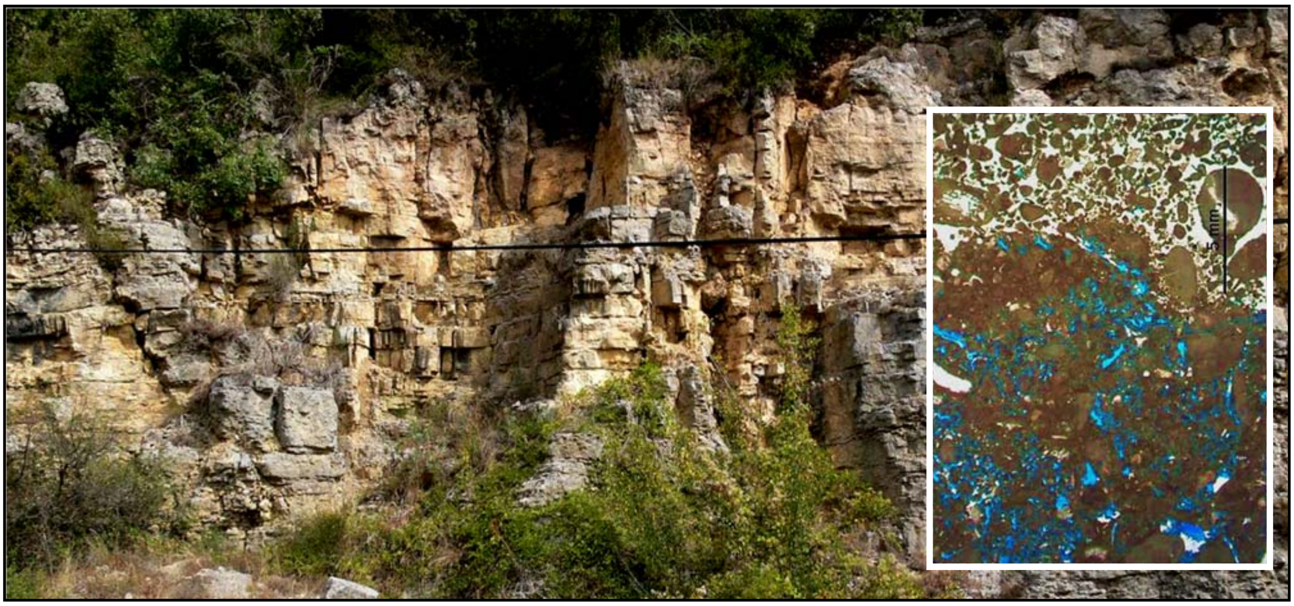


Fracture characterization

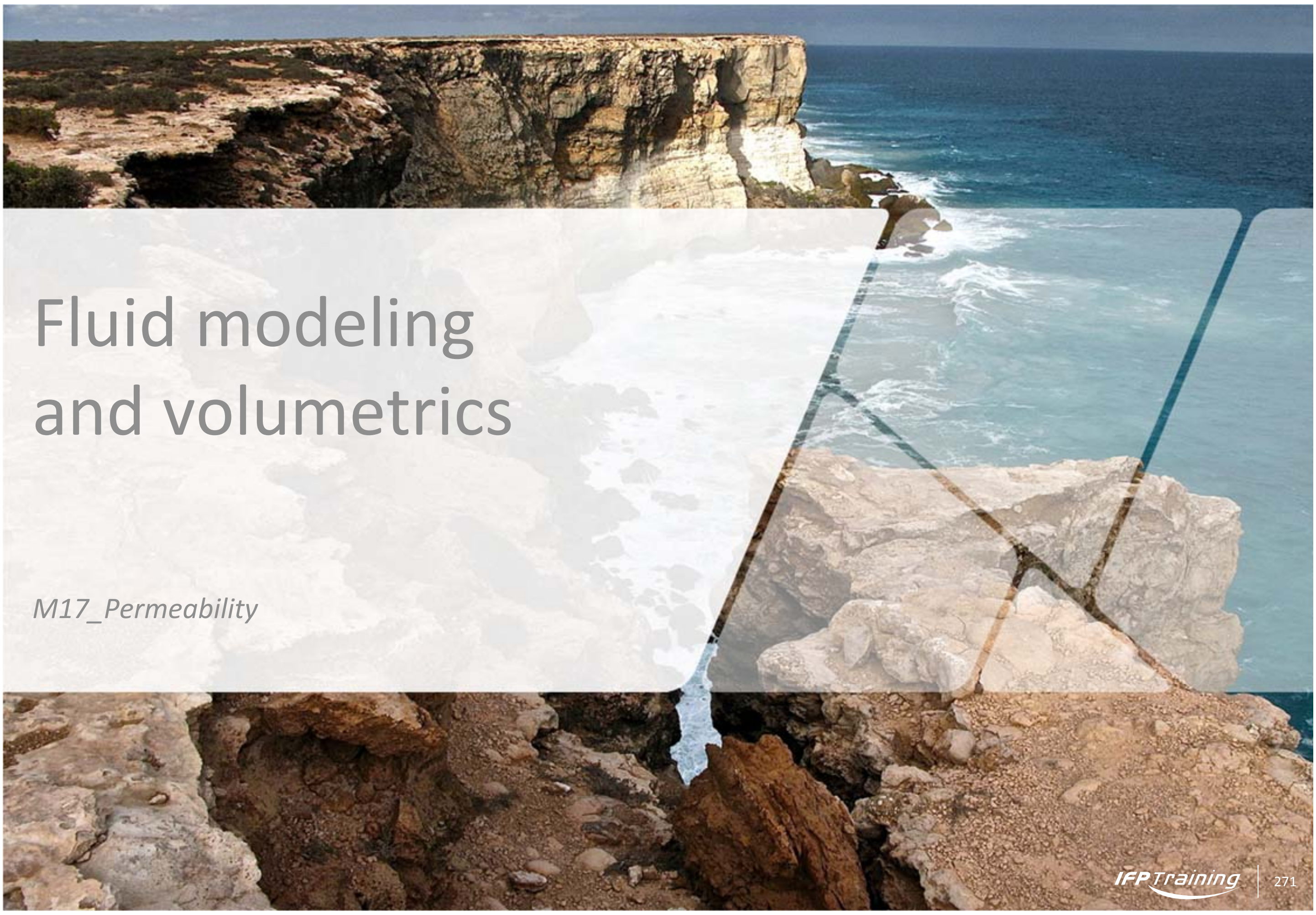


No fracture characterization in this case study

Diagenesis characterization



No diagenesis characterization in this case study

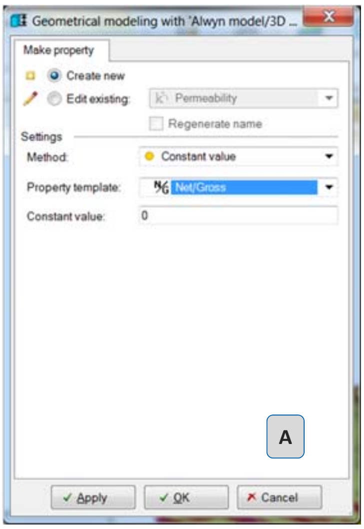


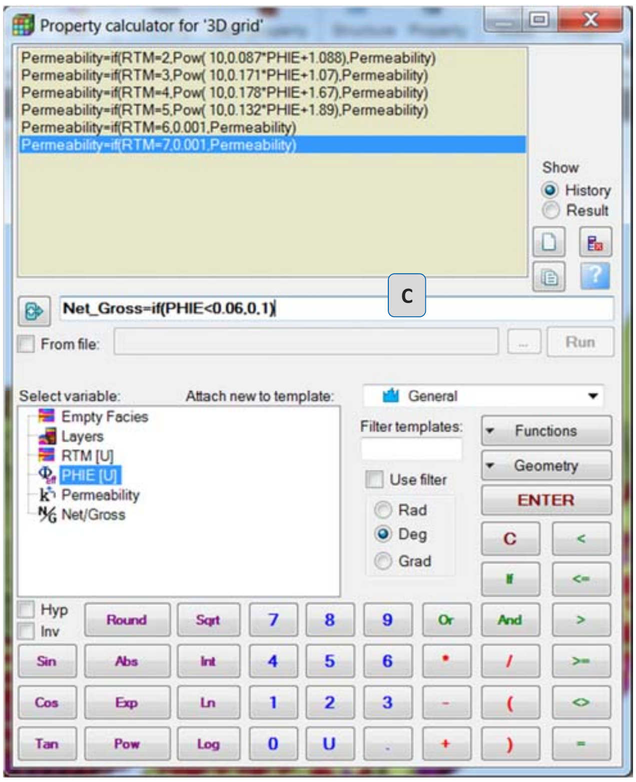
Fluid modeling and volumetrics

M17_Permeability

Net-to-Gross

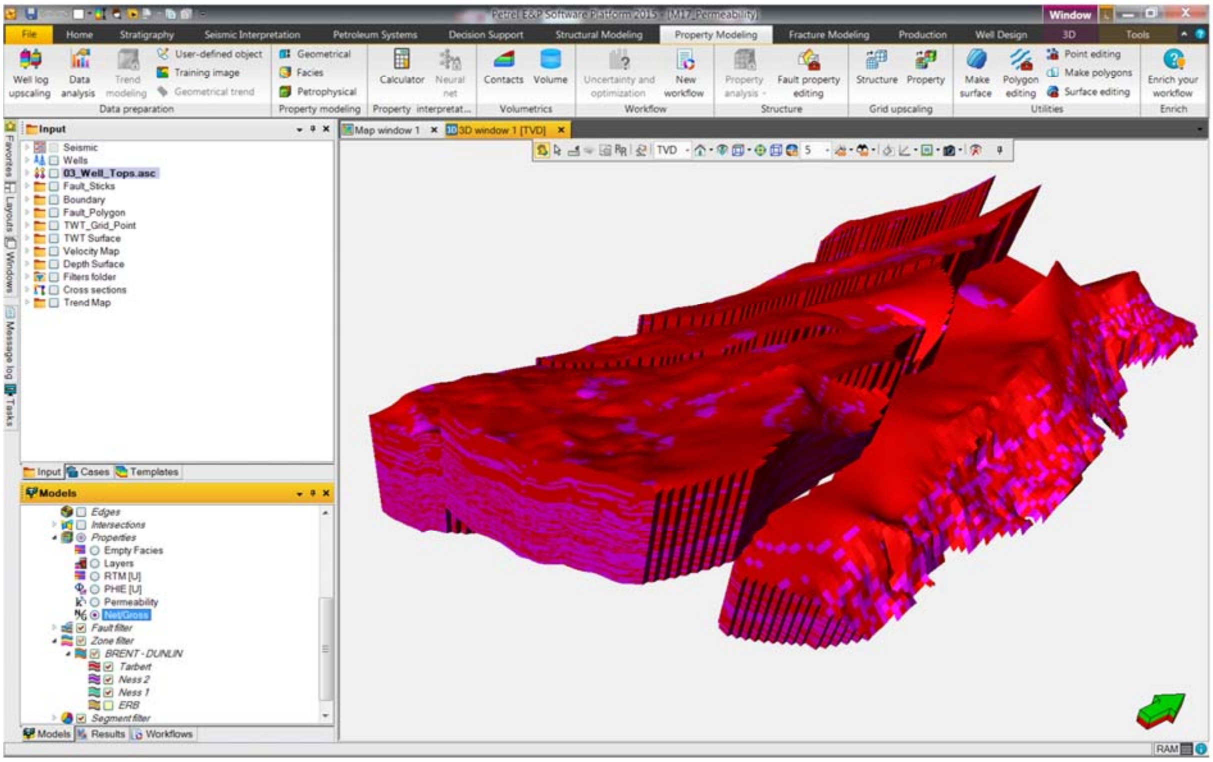
- **Build a Net-to-Gross variable**
  - Create a “Net/Gross” property in “Geometrical ” (A)
  - “Calculator” (B)
  - Type in formula: **Net_Gross=if(PHIE<0.06,0,1)** (C)





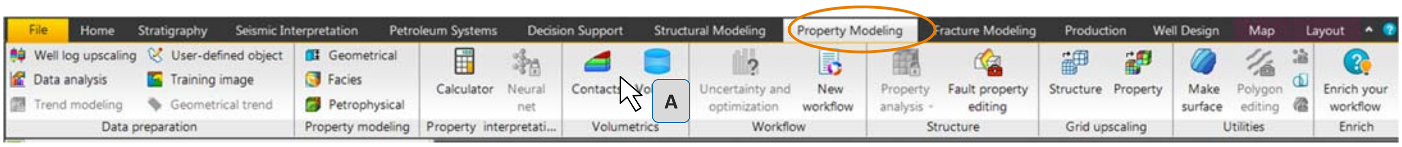
N2G is based on the Porosity model. All the cells with Porosity > 6% are considered with NTG = 1

M18_Net2Gross



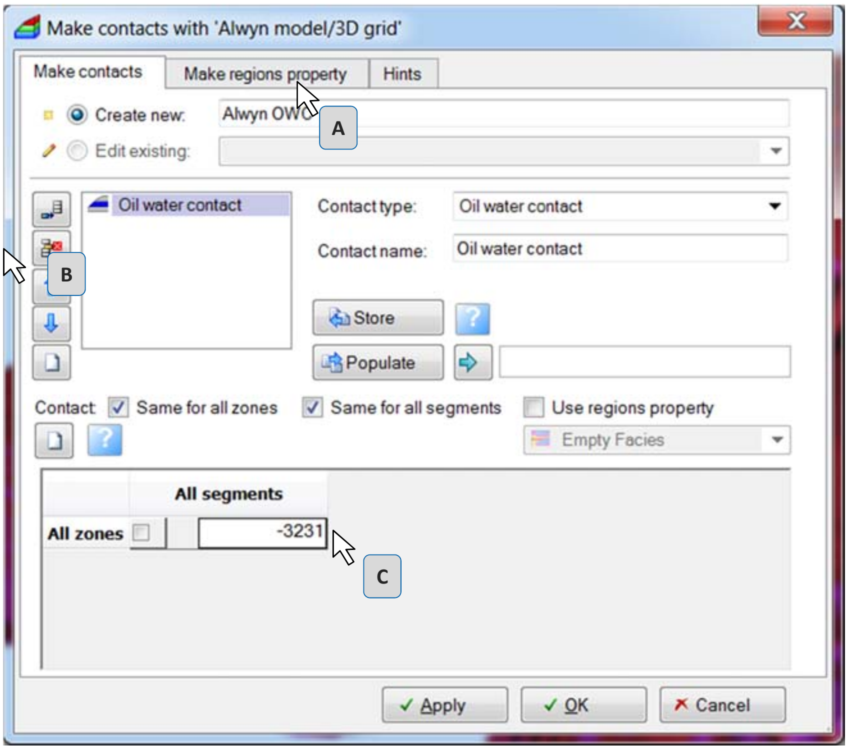
Create the fluid contact – 1/4

- **Define a WOC: first step for volumetric calculation**
  - Select “Contacts” (A)



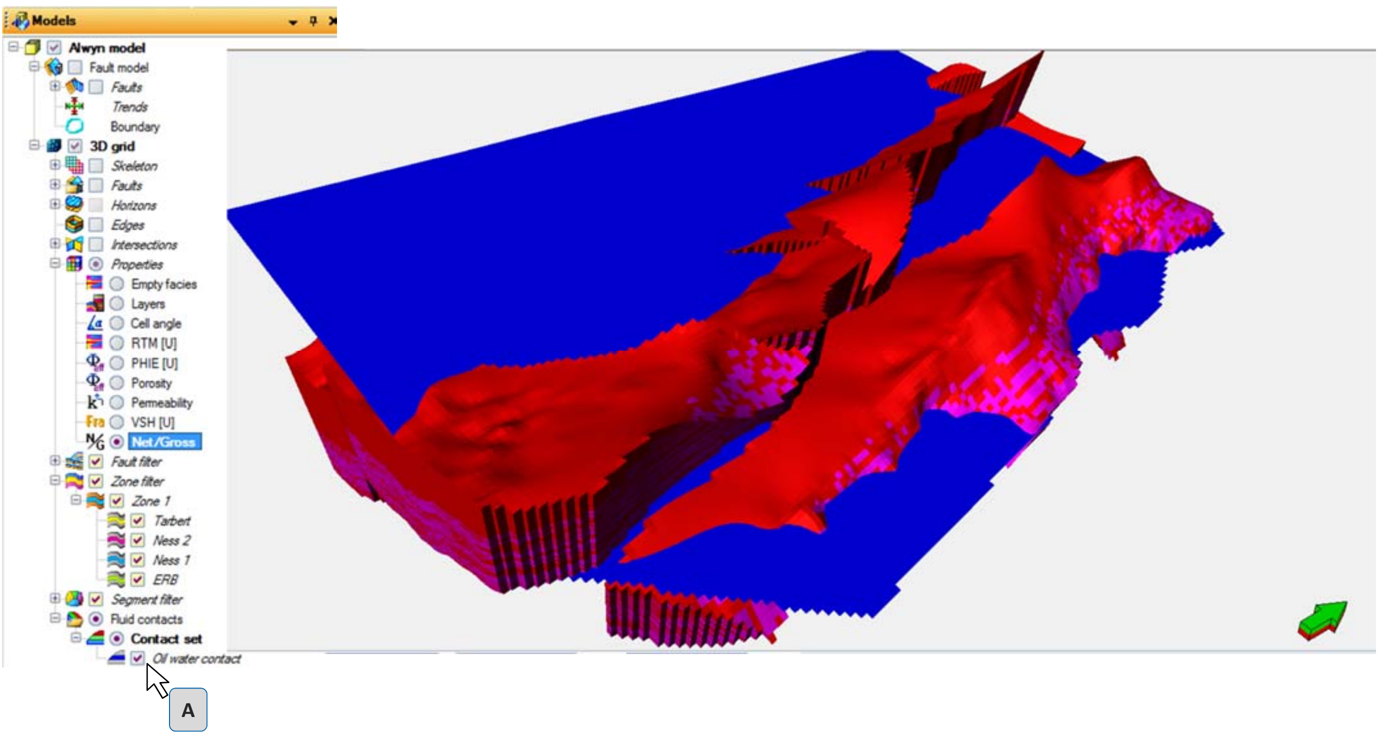
Create the fluid contact – 2/4

- Type in WOC name in "Create new". Enter Alwyn OWC (A)
- Choose "Contact type": "Oil water contact" and **remove other contacts** in list (B)
- Set WOC @ Z = **– 3231m** (C)
- Press "OK"
- The result appears at the end of "Models" tab
- Develop "Fluid contact" item; double click to select contact surface color and transparency level



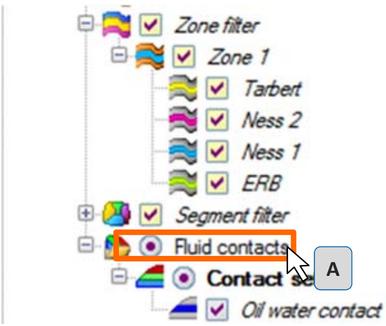
Create the fluid contact – 3/4

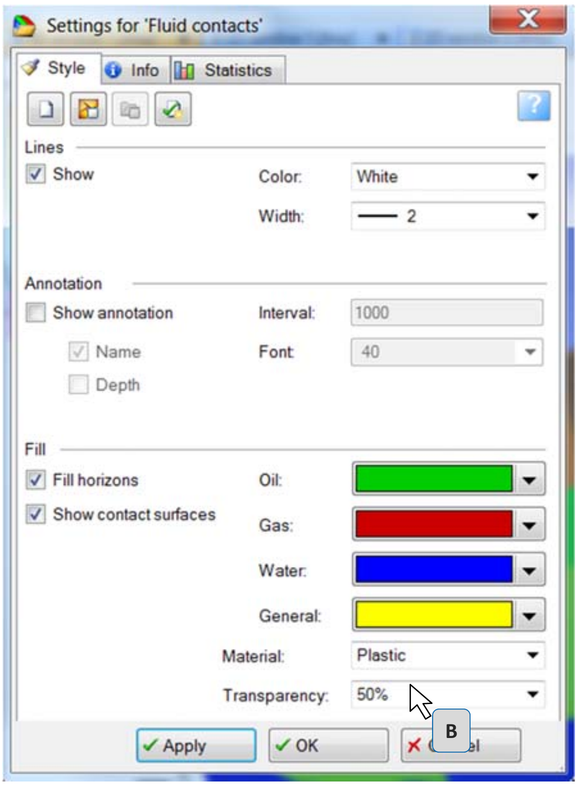
- Select Oil water contact (A)



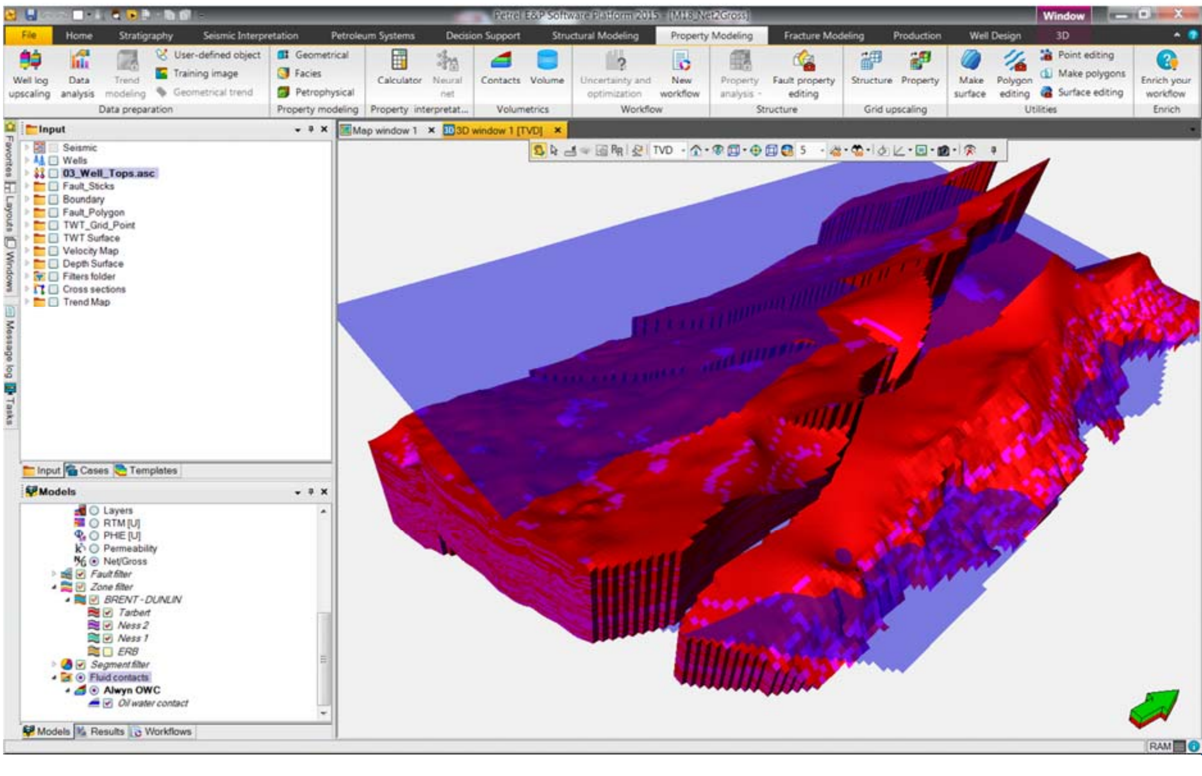
Create the fluid contact – 4/4

- The result appears at the end of the "Models" tab.
- Develop "Fluid contact" item; double click to select the contact surface color and transparency level.



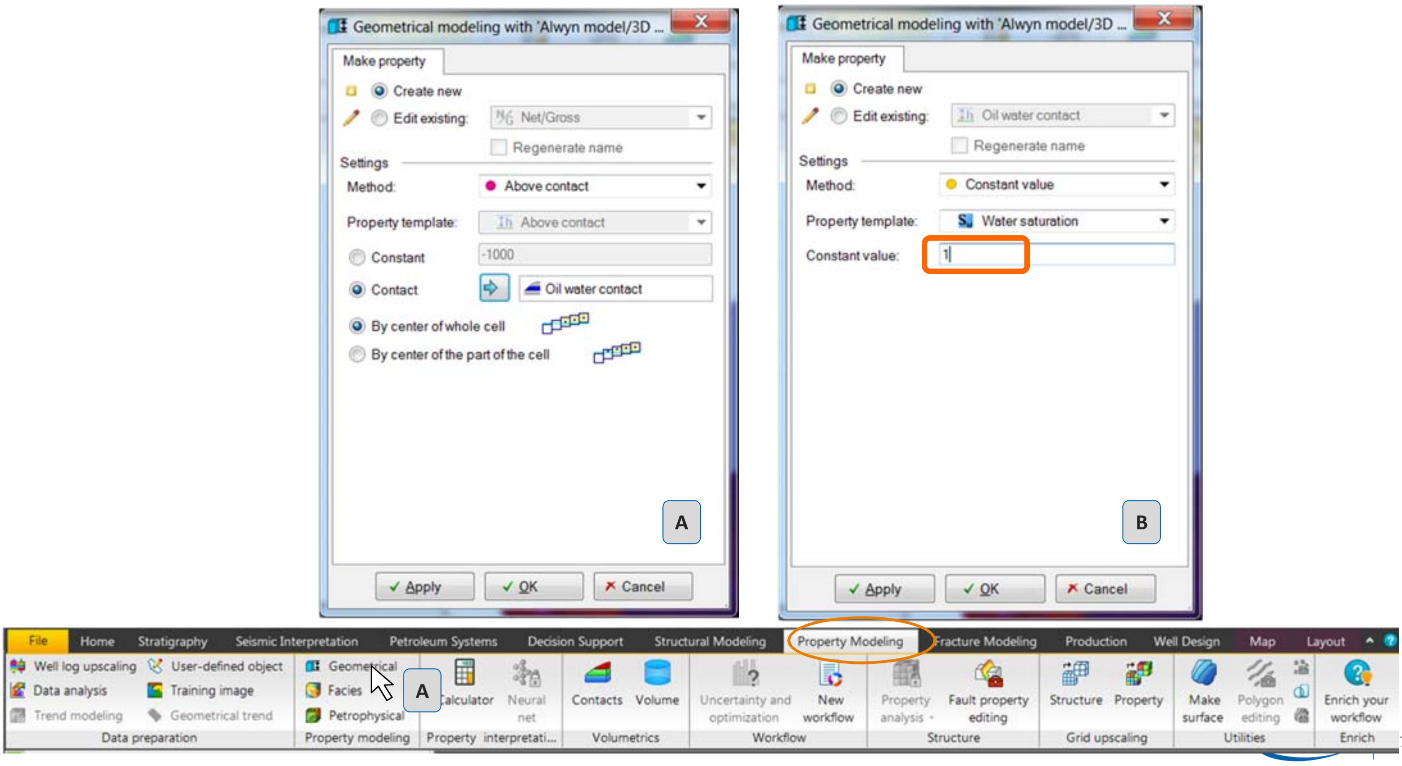


M19_Fluid



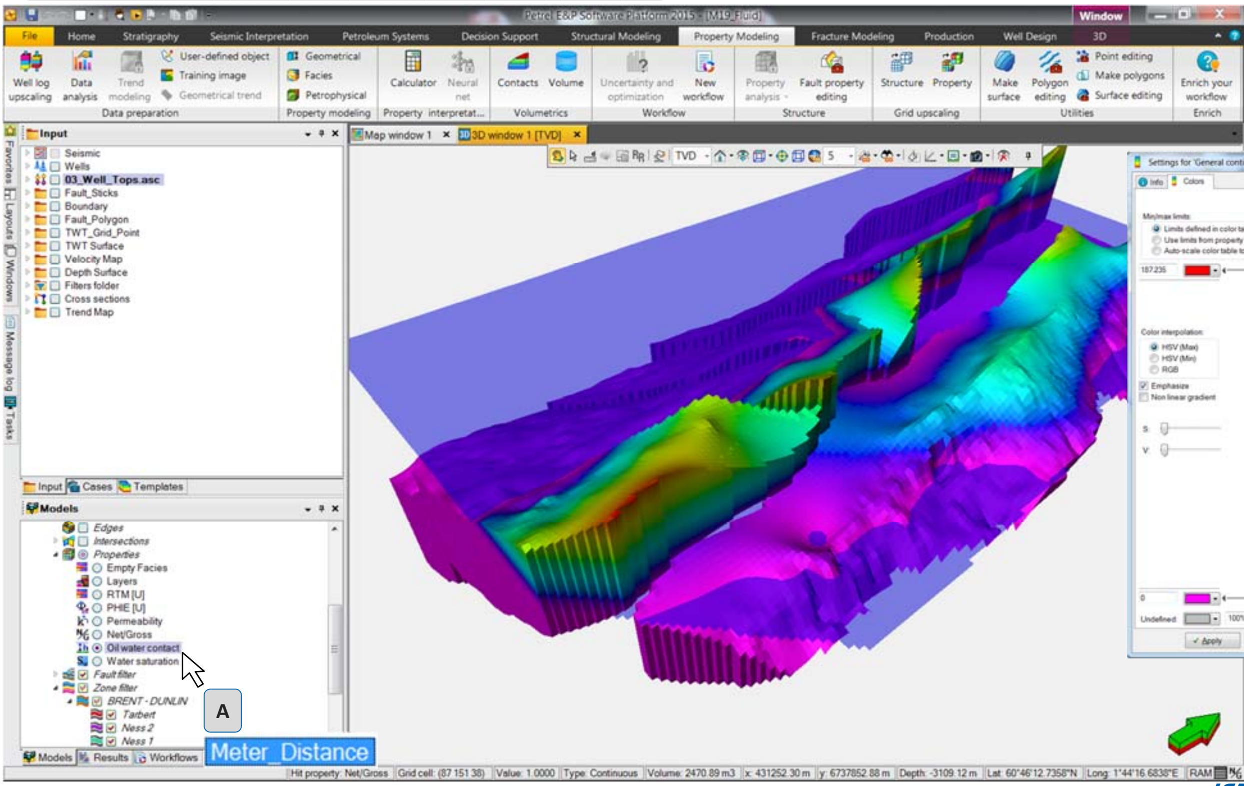
Water saturation

- **Create properties**
  - Above contact (distance between cell and OWC) (A)
  - Water saturation (B)

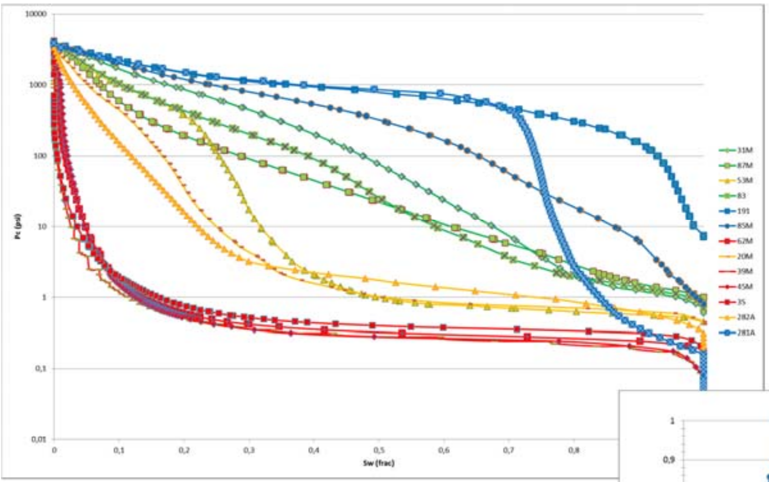


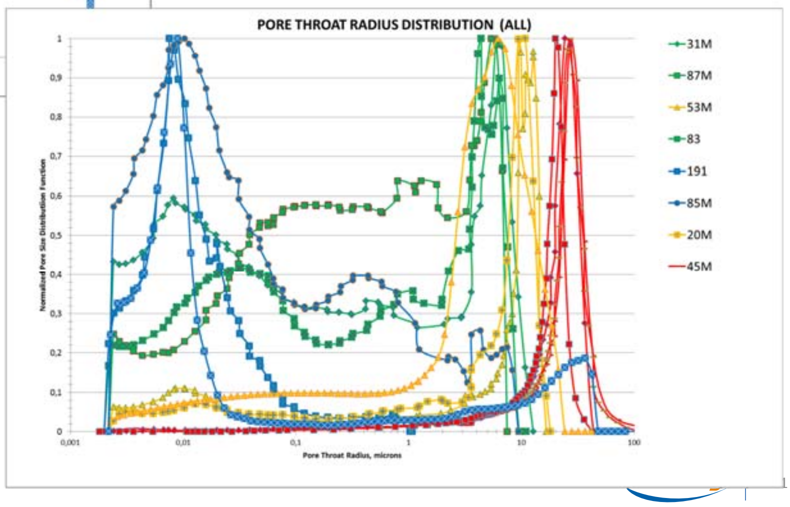
M20_Meter_Distance_OWC

- Select the Oil water contact model (A)
- Rename it as "Meter_Distance" and adjust the color scale



Water saturation





RHO Water (Kg/m3)	1102,064		
RHO Water (lb/ft3)	68,7996		
RHO Oil (Kg/m3)	872,24		
RHO Oil (lb/ft3)	54,452		
σCosθ (Res)	26		
C	Depend on the J fitting curve		
n	Depend on the J fitting curve		

Leverett J-Function

- In petroleum engineering, the **Leverett *J*-function** is a dimensionless function of water saturation describing the capillary pressure,

$$J\,(S_w) = \frac{p_c\,(Sw)\,\sqrt{k/\phi}}{\gamma\,\cos\theta}$$

where S_w is the water saturation measured as a fraction, pc is the capillary pressure (in Pascal), k is the permeability (measured in m^2), Φ is the porosity (0-1), γ is the contact angle. The function is important in that it is constant for a given saturation within a reservoir, thus relating reservoir properties for neighboring beds.

- The Leverett *J*-function is an attempt at extrapolating capillary pressure data for a given rock that are similar but with differing permeability porosity and wetting properties. It assumes that the porous rock can be modeled as a bundle of non-connecting capillary tubes, where the factor $\sqrt{k/\phi}$ is a characteristic length of the capillary radii.

Water saturation

$$J = \alpha.\frac{Pc}{\sigma Cos(\theta)}.\sqrt{\frac{K}{\phi}} = \alpha.\frac{(\rho_{water} - \rho_{oil})g.(z - FWL)}{\sigma Cos(\theta)}\sqrt{\frac{K}{\phi}}$$

$$J = \frac{0.001507\Delta\rho h}{\sigma Cos\theta}.\sqrt{\frac{K}{\phi}}$$

Where	
Δp: lb/ft3	Δp: (68.799-54.451)lb/ft3
σCos(θ): dynes/cm	26
h:ft	

$$J = 0.0008316(z - FWL).\sqrt{\frac{K}{\phi}}$$ (feet)

ft to meter ➔ multiply by 3.2808399

$$J = 0.00272835(z - FWL).\sqrt{\frac{K}{\phi}}$$ (meter)

	Rocktype	J-Fitting curve	C	n	Swi
	Clean SS	J=C.(Swr^n)	0,23	-0,75	0,08
	Radioactive SS	J=C.(Swr^n)	0,2	-0,9	0,19
	Micaceous SS	J=C.(Swr^n)	7	-7,7	0,33
	Silty Shale	J=C.EXP(Swr.n)	4,5	-0,7	0,72
	Swi data source come from laboratory analysis				

1/n =-1.333
1/n =-1.11
1/n =-0.1299

When J=C.(Swr^n) (Clean SS, Rad SS and Micaceous SS)

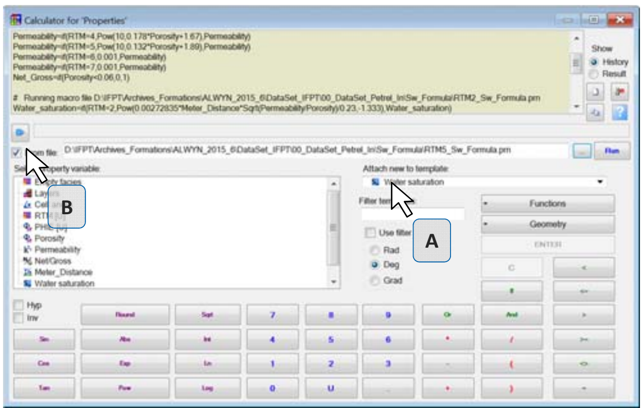
$$Swr = \left(\frac{0.00272835(z - FWL).\sqrt{\frac{K}{\phi}}}{C}\right)^{1/n}$$

When J=C.EXP(Swr.n) (Silty shale)

$$Swr = \frac{\ln\left(\frac{0.00272835(z - FWL).\sqrt{\frac{K}{\phi}}}{C}\right)}{n}$$

Water saturation

- Select the water saturation model
- Right click and calculator
- Attach a new “water saturation” template (A)
- Write each formula and enter (or load txt file with formula (B))



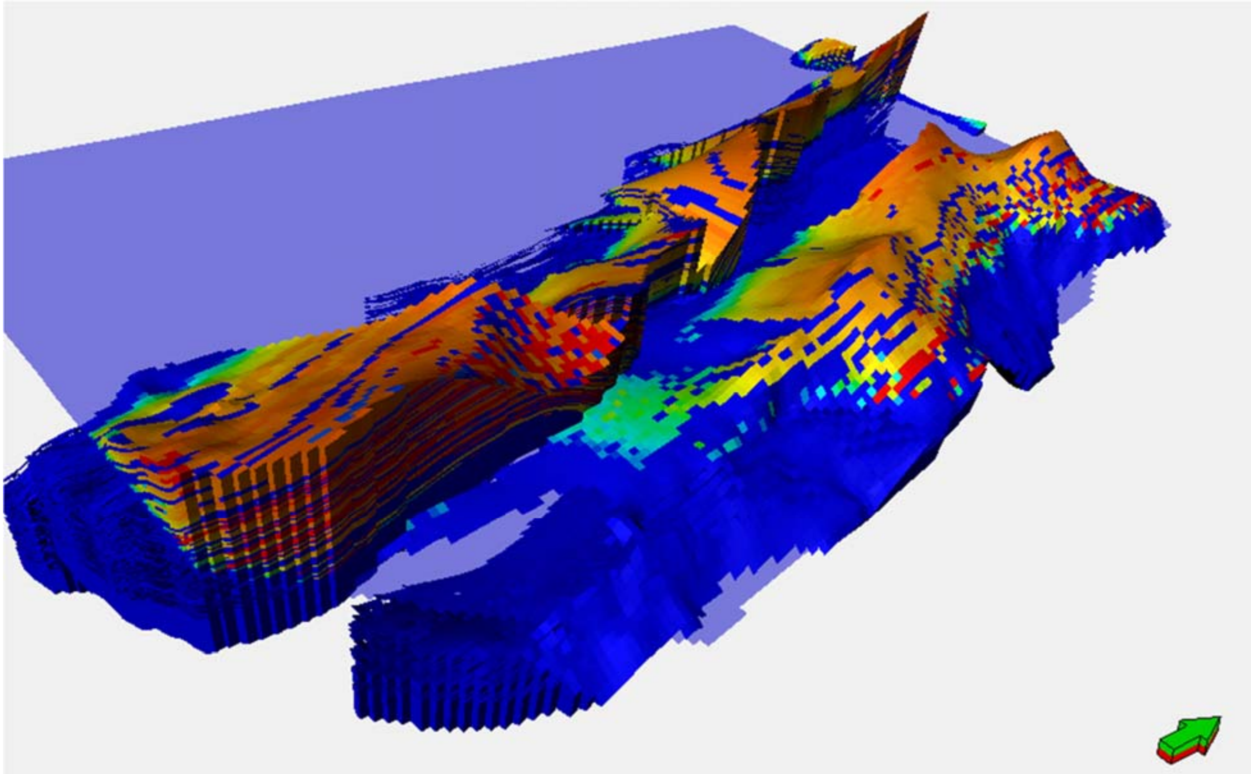
Water_saturation=if(RTM=2,Pow(0.00272835*Meter_Distance*Sqrt(Permeability/PHIE)/0.23,-1.333),Water_saturation)

Water_saturation=if(RTM=3,Pow(0.00272835*Meter_Distance*Sqrt(Permeability/PHIE)/0.2,-1.111),Water_saturation)

Water_saturation=if(RTM=4,Pow(0.00272835*Meter_Distance*Sqrt(Permeability/PHIE)/7,-0.1299),Water_saturation)

Water_saturation=if(RTM=5,(Ln(0.00272835*Meter_Distance*Sqrt(Permeability/PHIE)/4.5)/-0.7),Water_saturation)

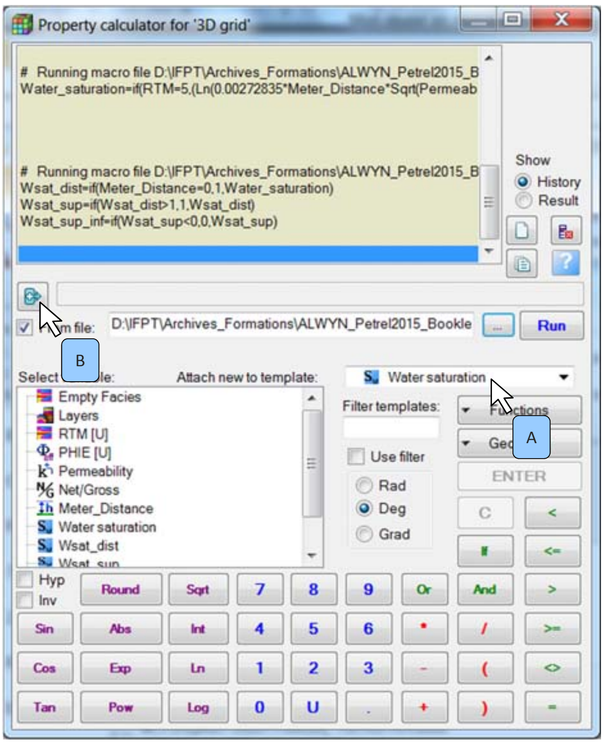
Water saturation



Water saturation

- **Adjust the Water saturation**
  - Right click and calculator
  - Attach a new “water saturation” template (A)
  - Type in each formula and enter (or load txt file “Z_Clipping_Thresholds_Sw.prn” with these formula (B))

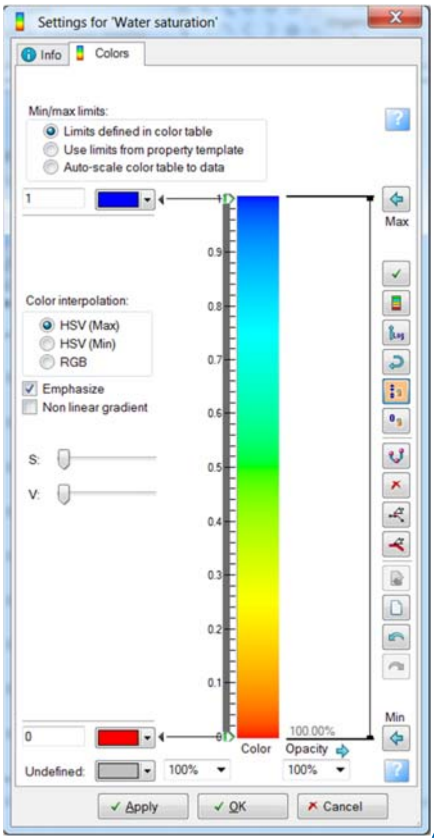
0 < Water Saturation < 1



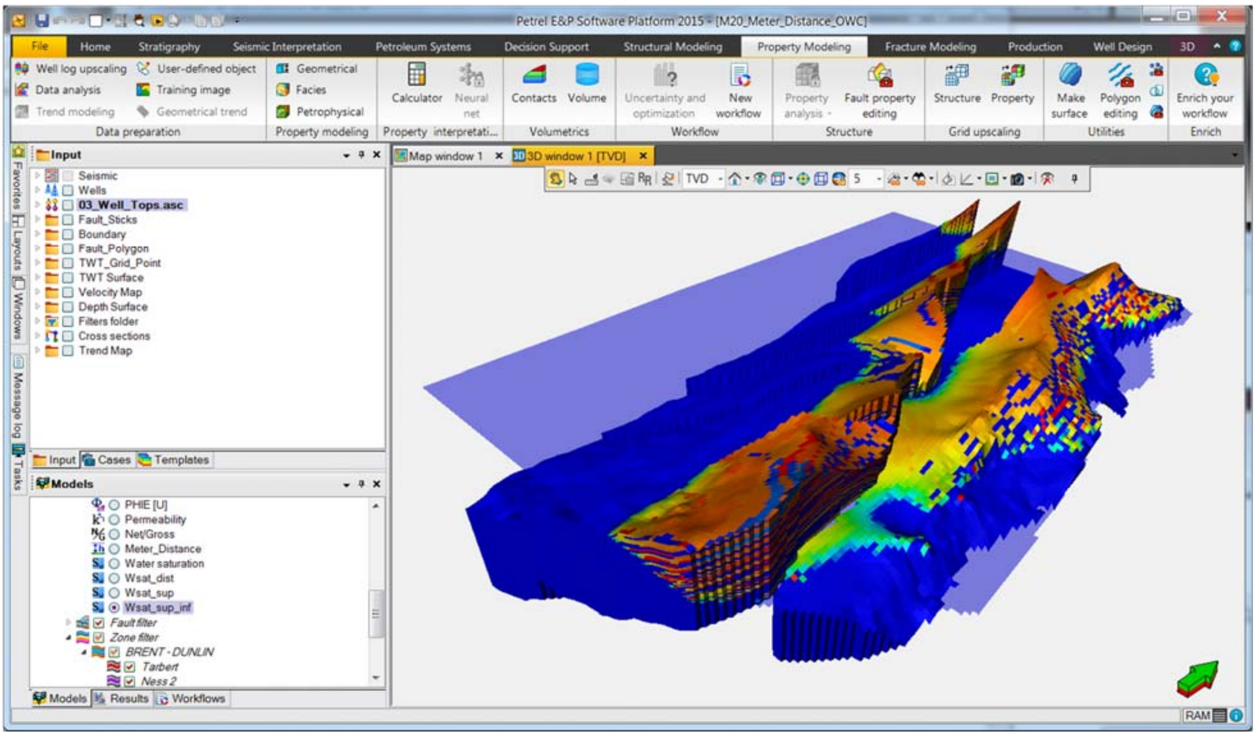
Wsat_dist=if(Meter_Distance=0,1,Water_saturation)
Wsat_sup=if(Wsat_dist>1,1,Wsat_dist)
Wsat_sup_inf=if(Wsat_sup<0,0,Wsat_sup)

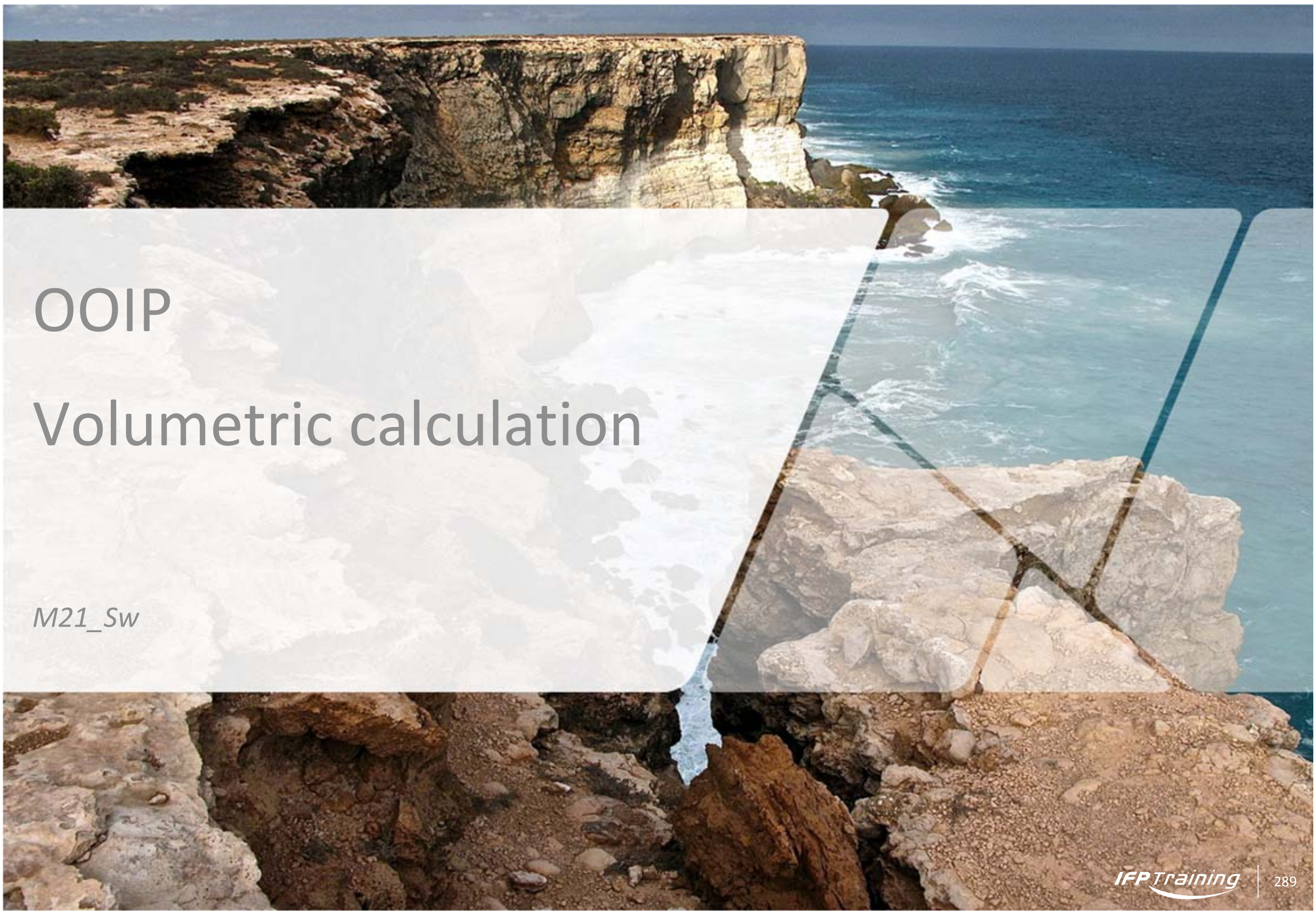
Water saturation

- **Select Wsat_Final**
- **Adjust the color scale**
  - Reverse the color scale (A)
  - Change min and max (B) and (C)



M21_Sw





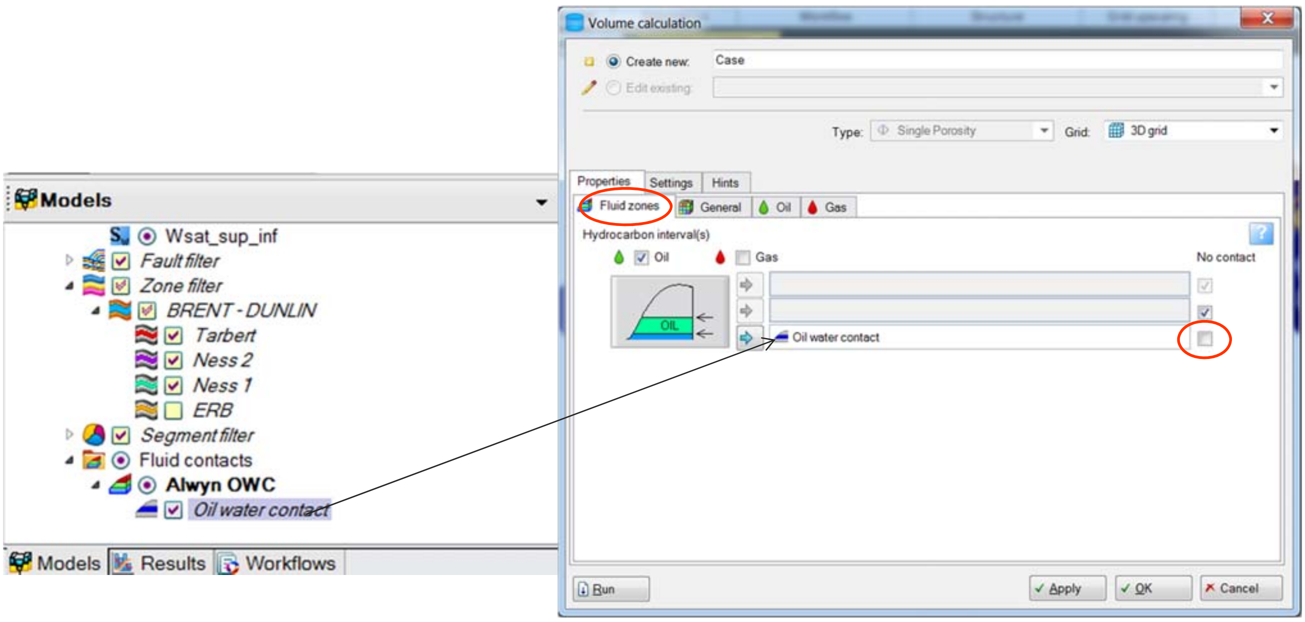
OOIP

Volumetric calculation

M21_Sw

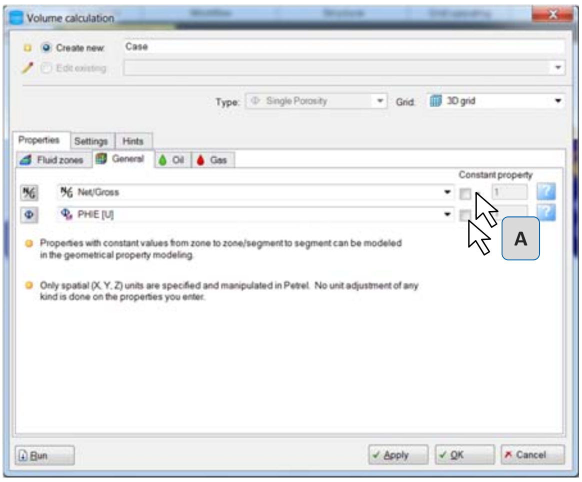
OOIP calculation

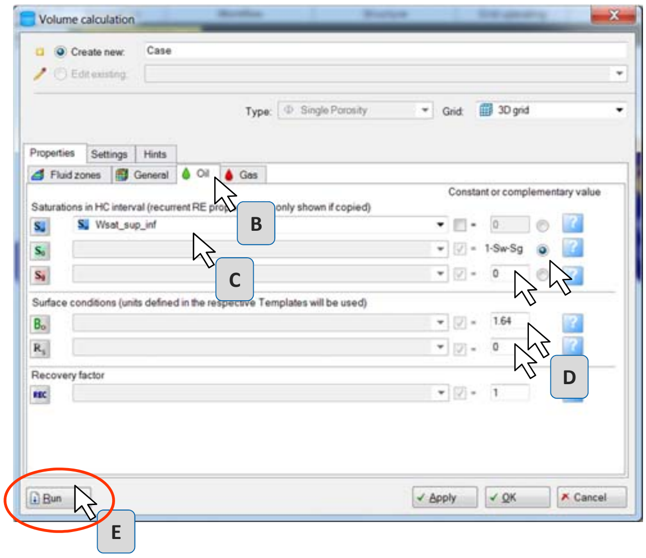
- **Reservoir model for in-place volumetrics (HIP)**
  - Select the “Utilities” panel and “Volume calculation”
  - Fluid zone index: select contact



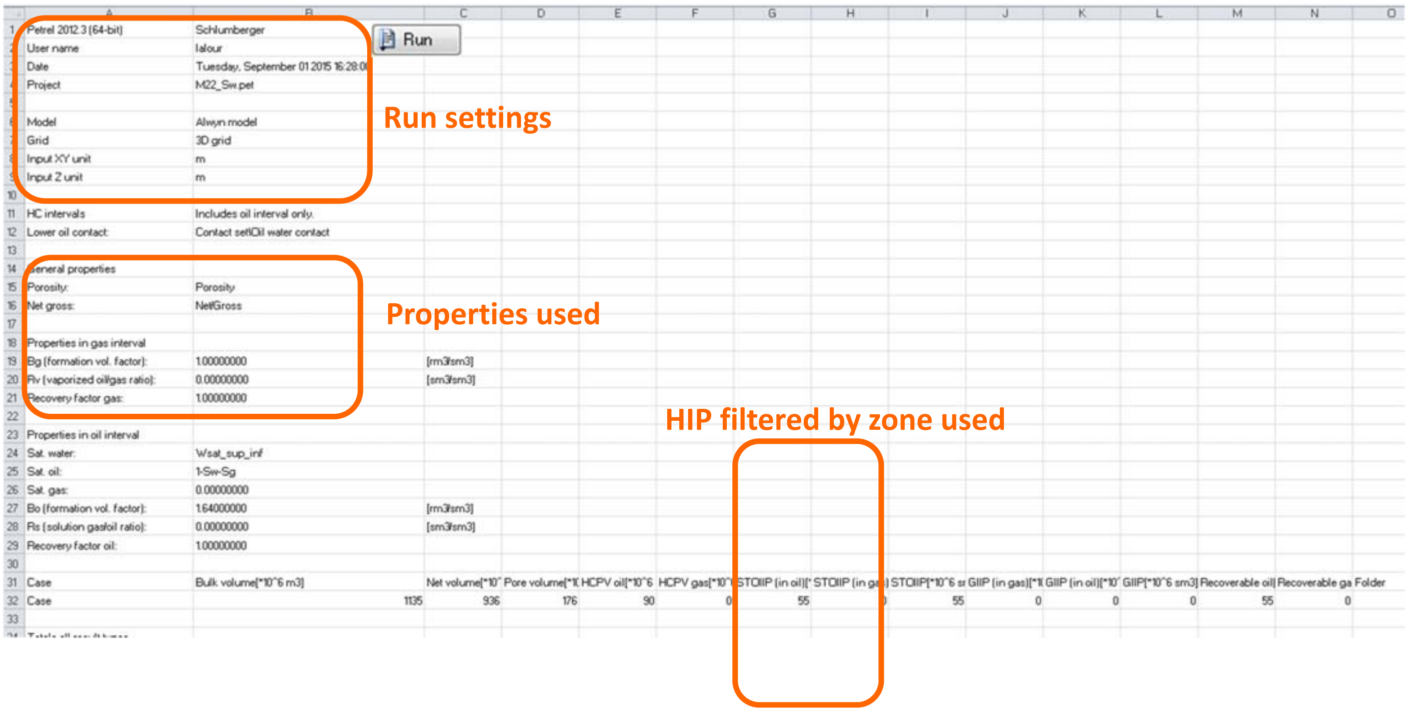
OOIP calculation

- **Reservoir model for in-place volumetrics**
  - “General” tab, select the computed properties: Net/Gross and Porosity (A)
  - In “Properties” → “Oil” tab(B), select the computed property Wsat_Final (C)
  - Type in fluid properties as follows: **Sg = 0; Bo = 1.64 (C)**
  - Press “Run”: the results automatically appear in a table (E)

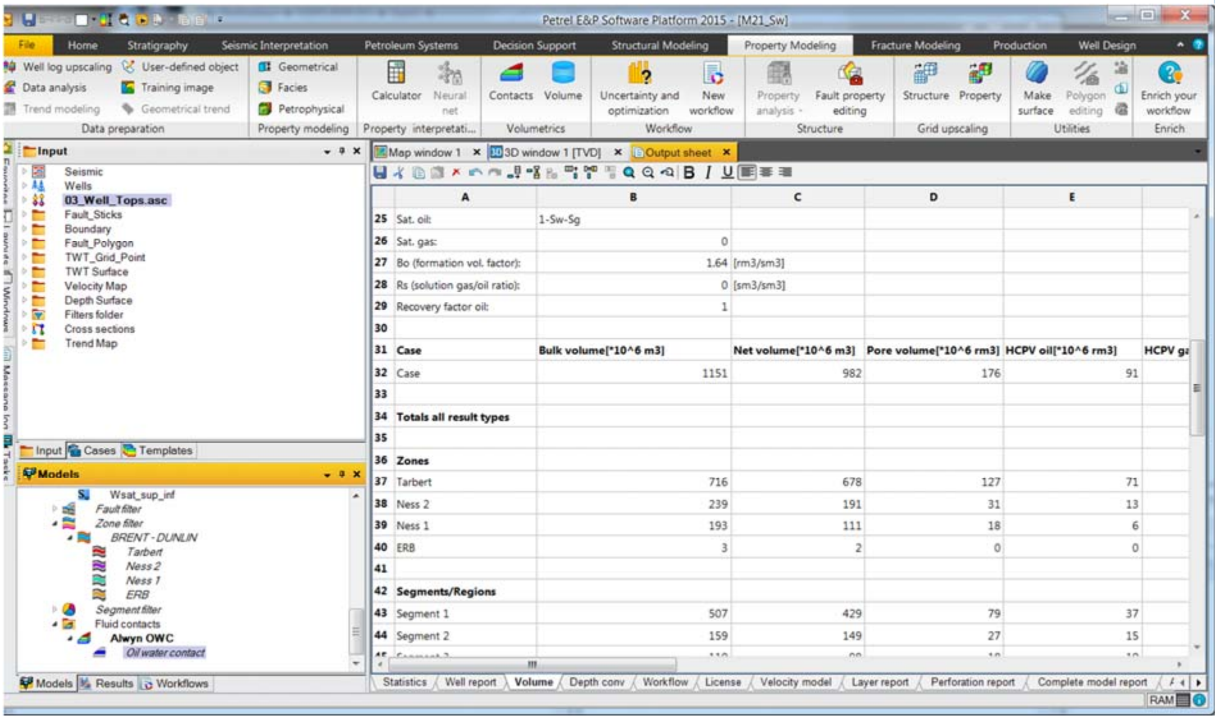




OOIP calculation – Volumetric report



M22_OOIP



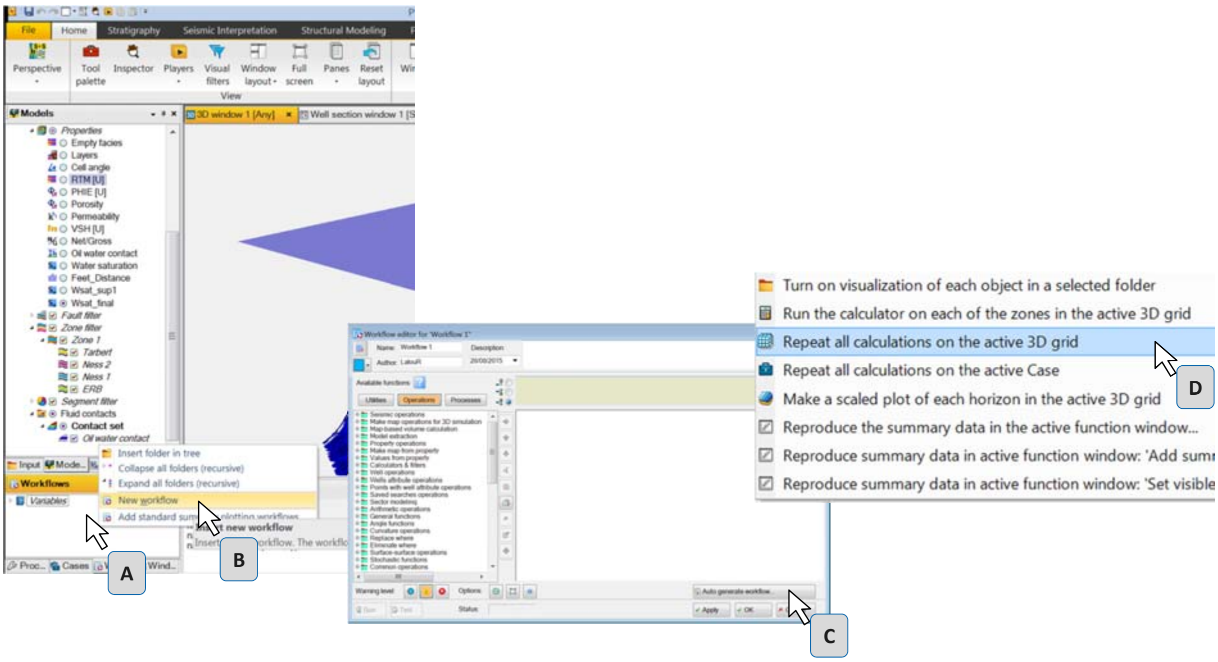
Petrel E&P Software Platform 2015 - [M21_Sw]
File
Home
Stratigraphy
Seismic Interpretation
Petroleum Systems
Decision Support
Structural Modeling
Property Modeling
Fracture Modeling
Production
Well Design
Input
Seismic
Wells
03_Well_Tops.asc
Fault_Sticks
Boundary
Fault_Polygon
TWT_Grid_Point
TWT Surface
Velocity Map
Depth Surface
Filters folder
Cross sections
Trend Map
Models
Wsat_sup_inf
Fault filter
Zone filter
BRENT - DUNLIN
Tarbert
Ness 2
Ness 1
ERB
Segment filter
Fluid contacts
Alwyn OWC
Oil water contact
Map window 1
3D window 1 [TVD]
Output sheet
25 Sat. oil: 1-Sw-Sg
26 Sat. gas: 0
27 Bo (formation vol. factor): 1.64 [rm3/sm3]
28 Rs (solution gas/oil ratio): 0 [sm3/sm3]
29 Recovery factor oil: 1
31 Case | Bulk volume[*10^6 m3] | Net volume[*10^6 m3] | Pore volume[*10^6 rm3] | HCPV oil[*10^6 rm3]
32 Case 1151 982 176 91
34 Totals all result types
36 Zones
37 Tarbert 716 678 127 71
38 Ness 2 239 191 31 13
39 Ness 1 193 111 18 6
40 ERB 3 2 0 0
42 Segments/Regions
43 Segment 1 507 429 79 37
44 Segment 2 159 149 27 15
Statistics
Well report
Volume
Depth conv
Workflow
License
Velocity model
Layer report
Perforation report
Complete model report

Workflows and Uncertainties

M23_OOIP

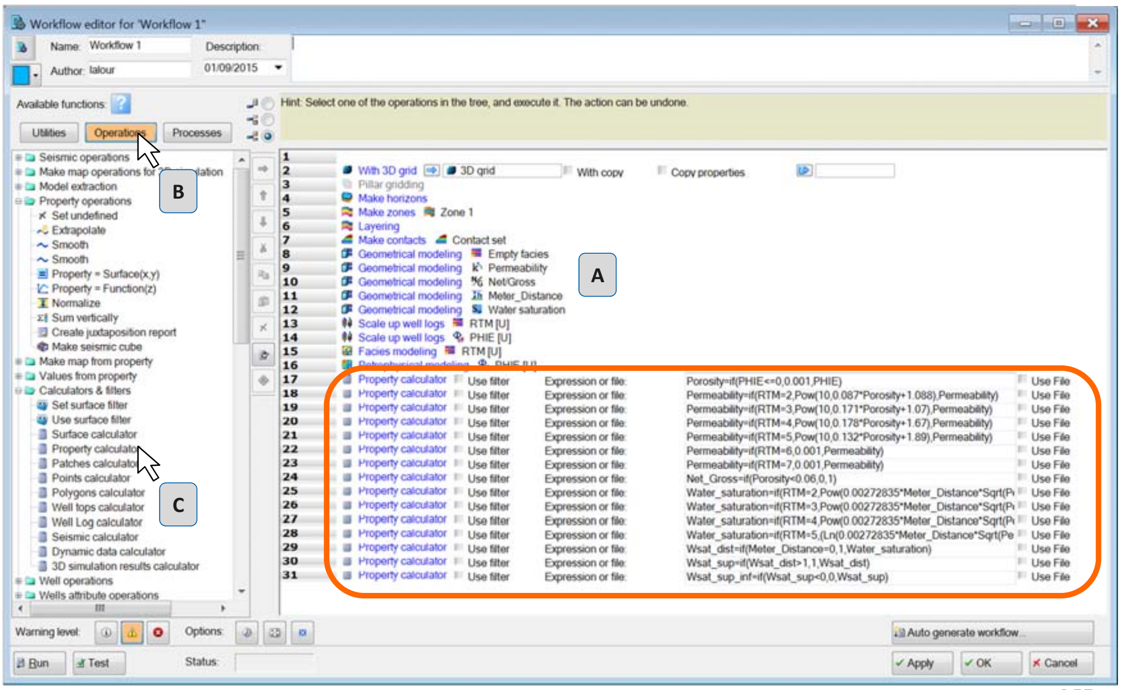
Build a workflow

- **Build WorkFlow Step 1**
  - Select the Workflows panel (A)
  - Right click and “New workflow” (B)
  - Click on the “Auto generate workflow” Button (C)
  - Select “Repeat all calculations in the active 3D grid” (D)



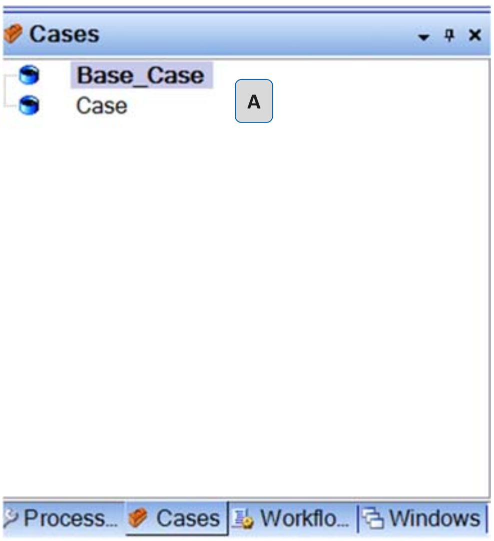
Build a workflow – M24_WFL

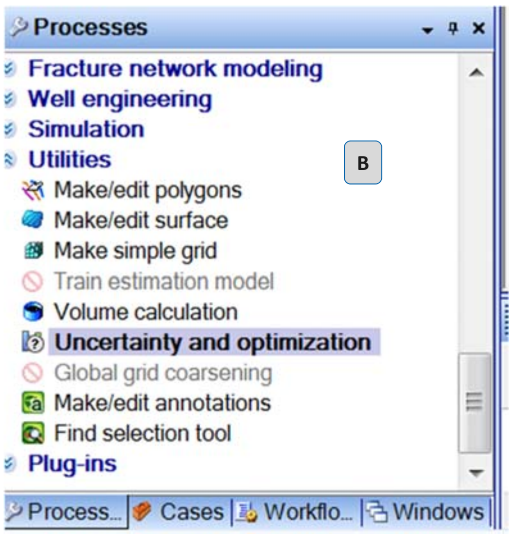
- **Build WorkFlow Step 2**
  - The workflow proposes all the modeling step
  - Click on “Operation” and select Property Calculation(C) to create a line with the calculation expression used during the modeling step



Uncertainties and optimization

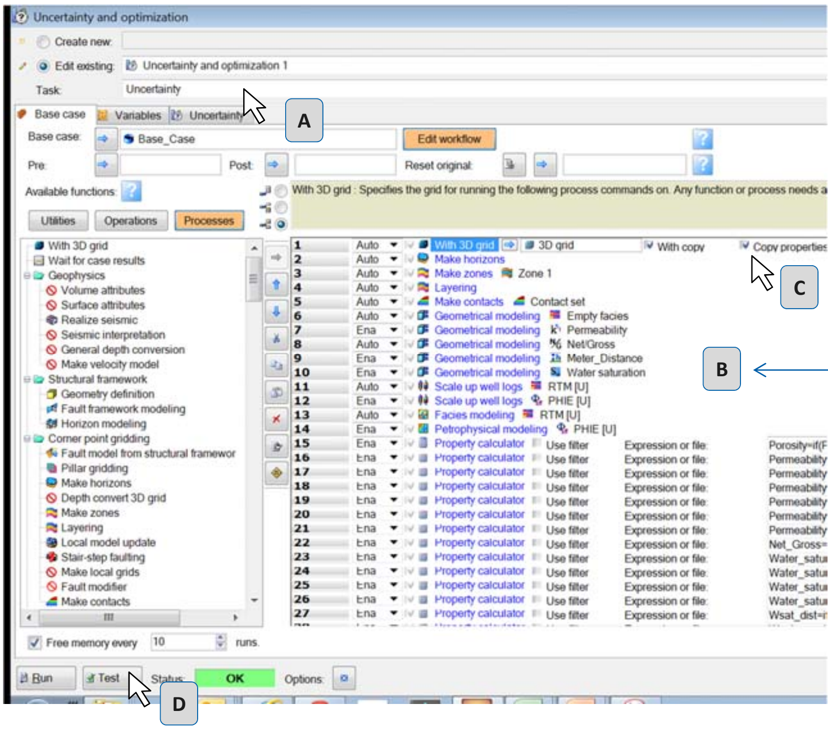
- **Uncertainties and optimization Step 1**
  - Copy /Paste Case to create Base_Case
  - Processes → Uncertainties and optimization



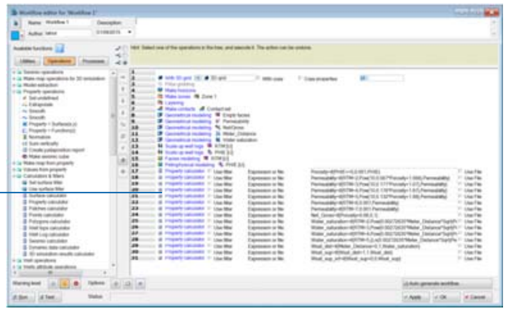


Uncertainties and optimization

- **Uncertainties and optimization Step 2**
  - Task: Uncertainties (A)
  - The workflow must be same as “WorFlow index. Use copy and paste (B)
  - Thick “copy properties” (C)
  - Test (D)

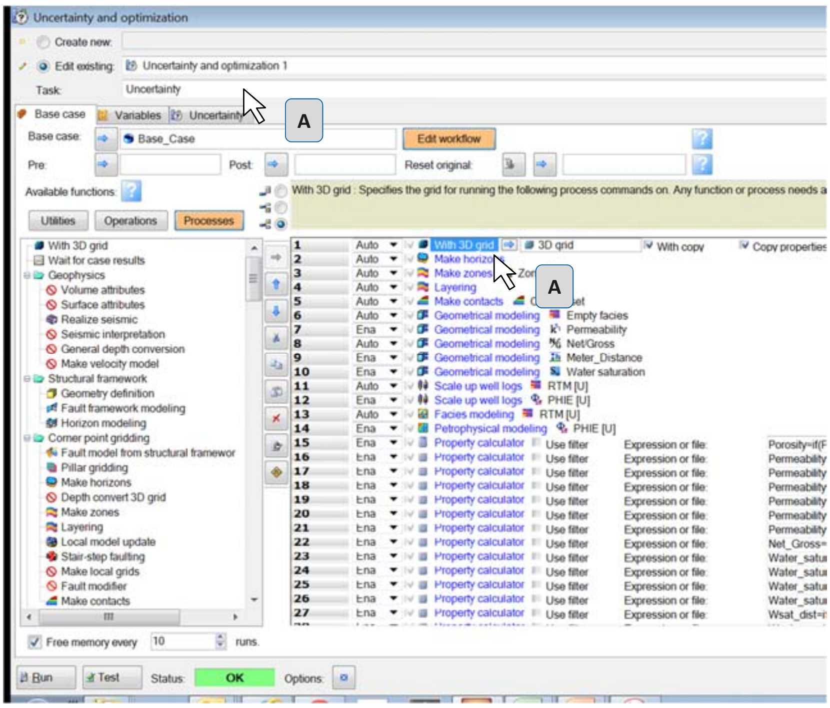


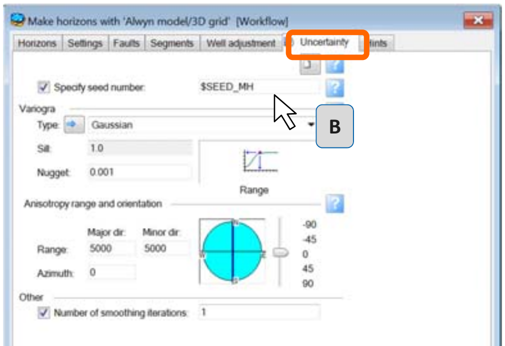
From the WorkFlow window, copy and paste each line



Uncertainties workflow – Structural modeling

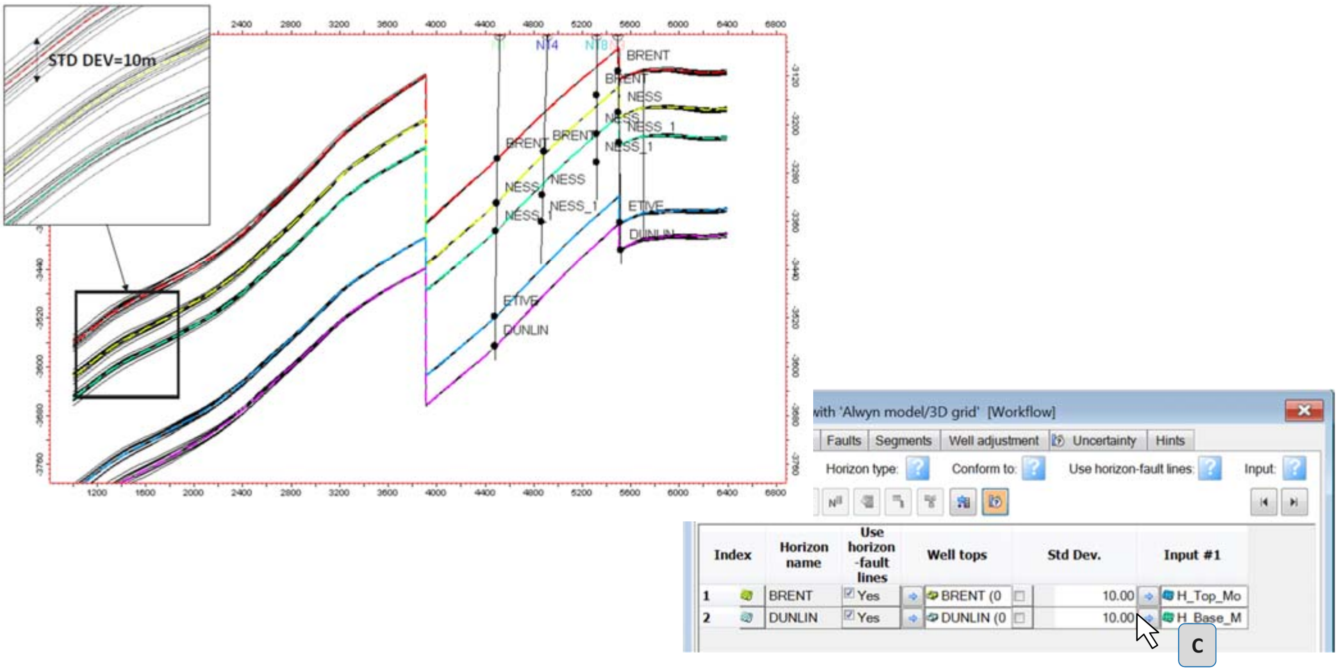
- **Structural uncertainties step 1**
  - Double click on “Make horizon” (A)
  - Select Uncertainties Index and change the seed value by “$SEED_MH “(B)





Uncertainties workflow – Structural modeling

- **Structural uncertainties step 2**
  - and change the seed value by “$SEED_MH “(A)



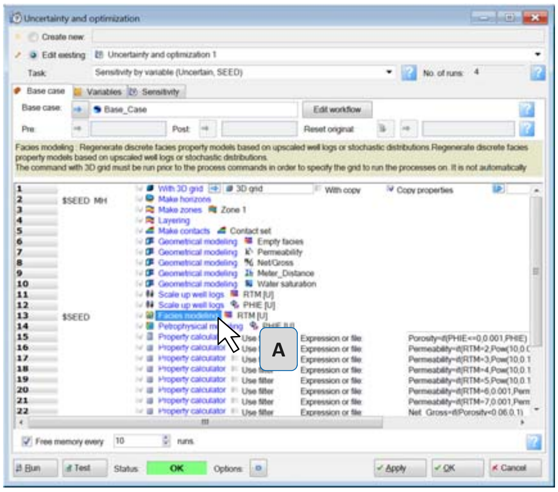
Uncertainties

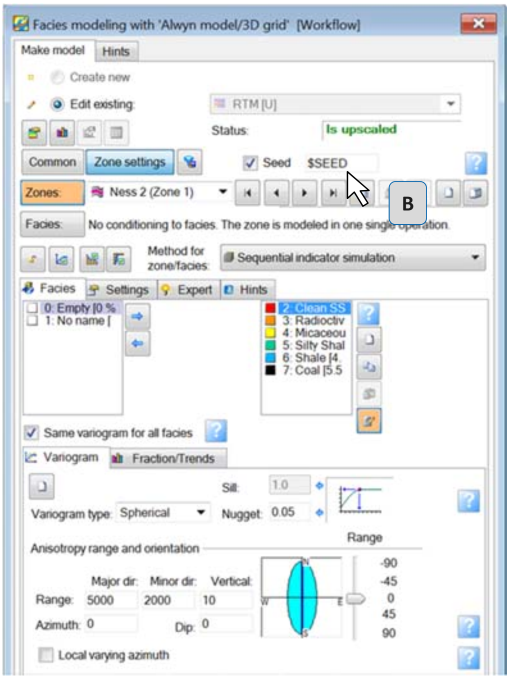
- **Stochastic Uncertainties**
  - Select Uncertainties Index (A)
  - Choose “Uncertainties Task” (B)
  - Choose a number of loops(B)
  - Run (D)

Philosophies
Mettre l’exercice du bouquin jungle où il est montré que la moyenne des avis individuels produit un résultat plus juste.

Uncertainties workflow – Facies modeling

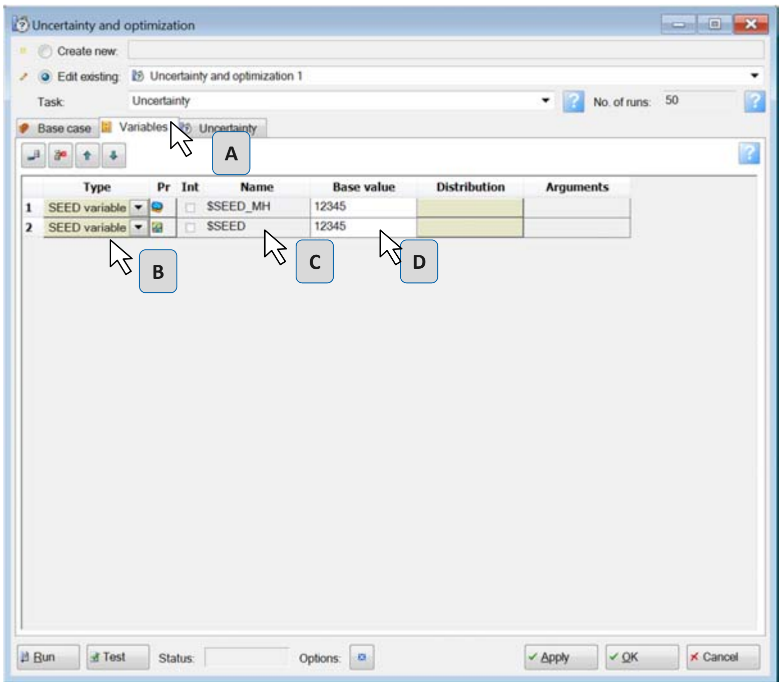
- **Stochastic Uncertainties**
  - Double click on “Facies modeling” (A)
  - Change Seed value as “$SEED (B)





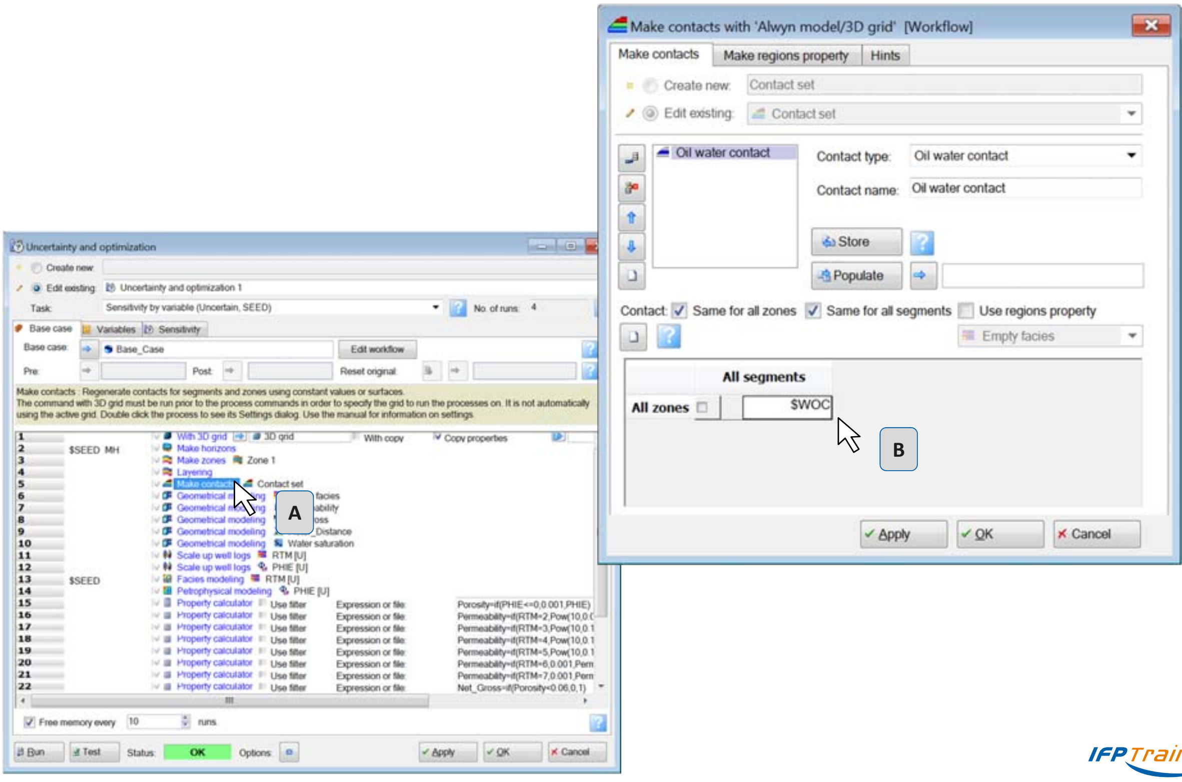
Uncertainties workflow – Variables

- **Declare variable**
  - Select the Variables panel (A)
  - Choose SEED variable (B)
  - Write $SEED_MH (for make horizon variable) and $SEED for geomodeling variable (C)
  - Choose a base value we propose 12345 (D)



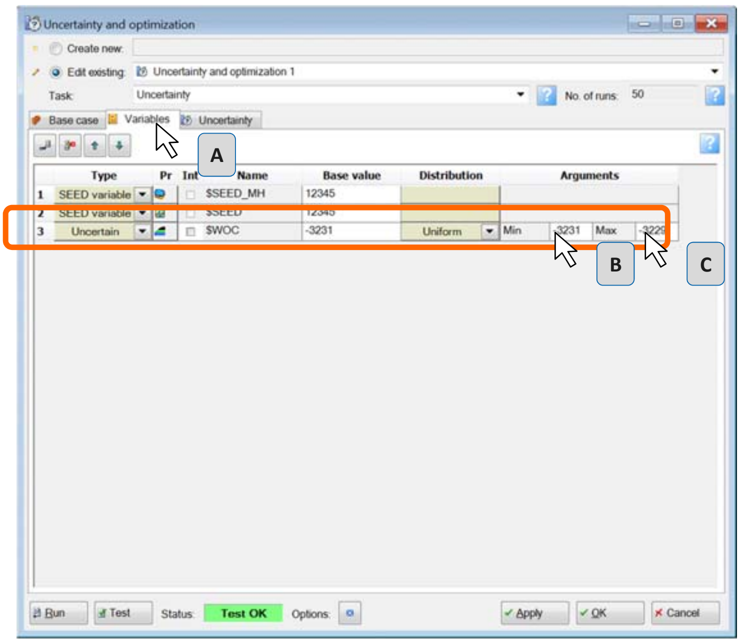
Uncertainties workflow – WOC modeling

- **Stochastic Uncertainties**
  - In the Workflows window (A) select "Uncertainties and optimization" (B)
  - Change the Seed value as "$WOC (B)



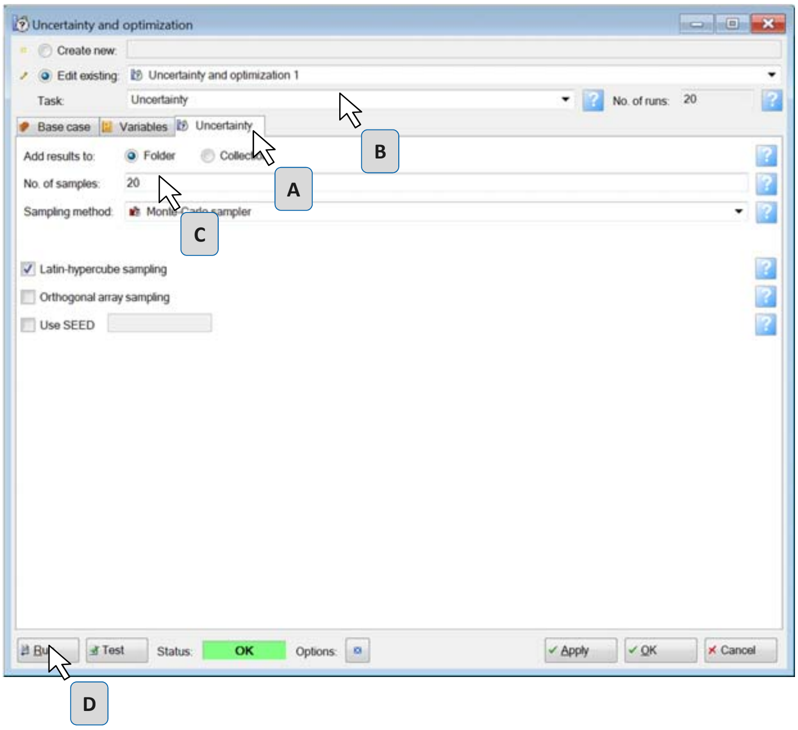
Uncertainties workflow – WOC modeling – M25_UncertaintiesWF

- **Stochastic Uncertainties**
  - Select "Variables" (A)
  - Fill Base value, min (-3231) and max (-3229) for WUT and ODT (B) and (C)



Uncertainties and optimization – M26_Uncertainties_100

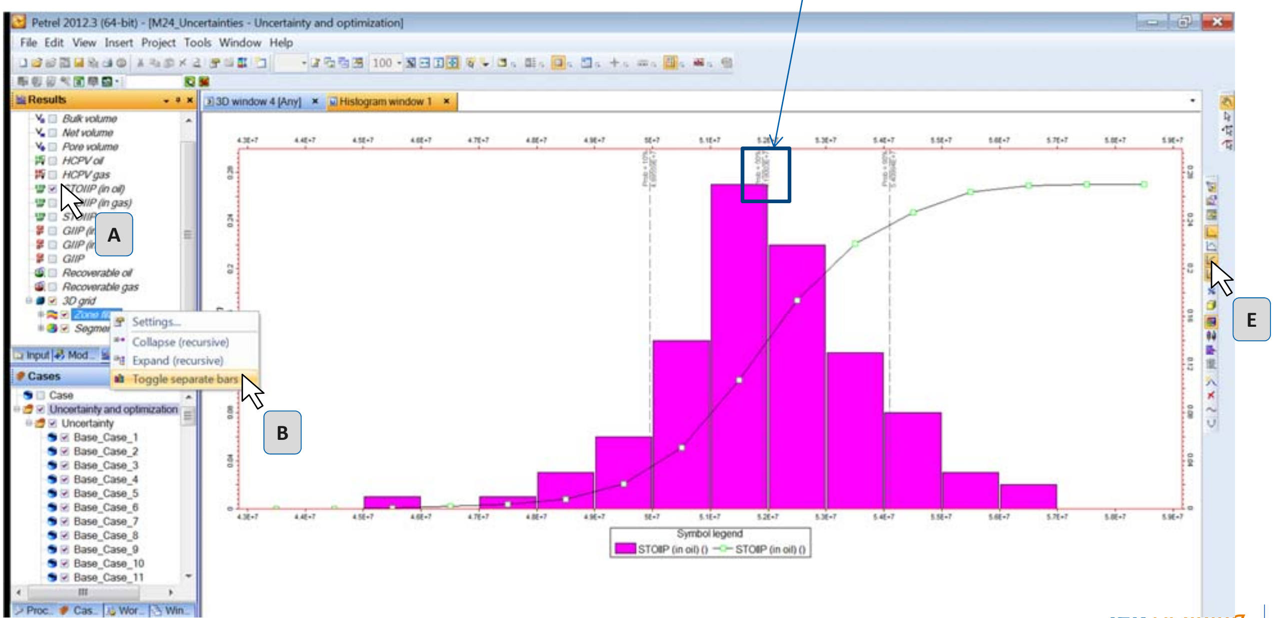
- **Uncertainties and optimization Step 3**
  - Select the Uncertainties Index (A)
  - Choose “Uncertainties Task” (B)
  - Choose a number of loops(B)
  - Run (D)



Uncertainties and optimization

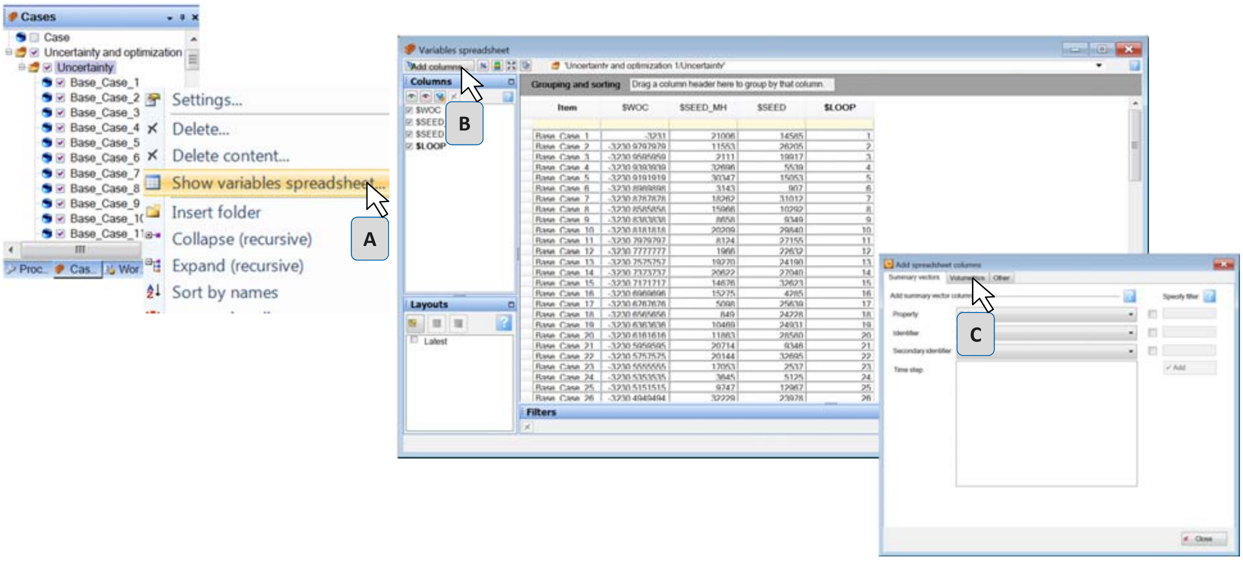
- **To display the results**
  - Open a new window named “Histogram window”
  - Select the result tab and STOOIP (B)
  - Select 3D grid → Zone filter and right click “Toggle separate bar” (C)
  - Use Icon “Show CDF curve” to Cumulative density function (D)
  - Read Volume for P50

P50 = 51.9 E+6



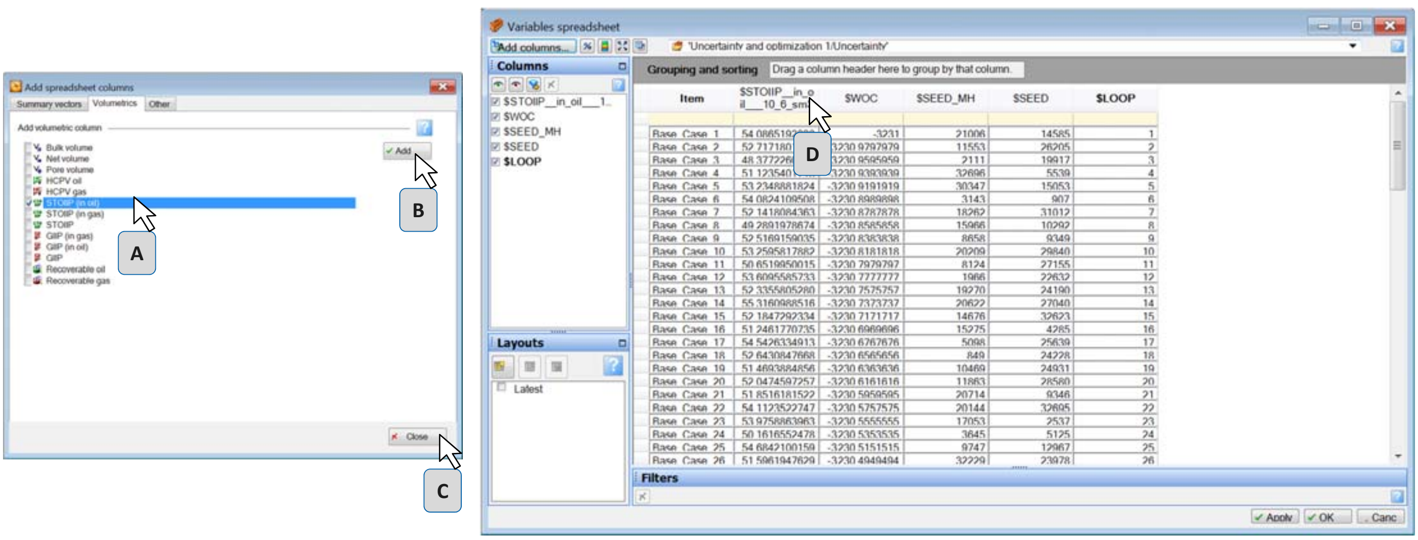
Uncertainties and optimization – Table

- **To display results**
  - Select Case → Uncertainty. Right click and "Show variable on Speadsheet" (A)
  - Click on "Add column" (B) and select "Volumetric" (C)



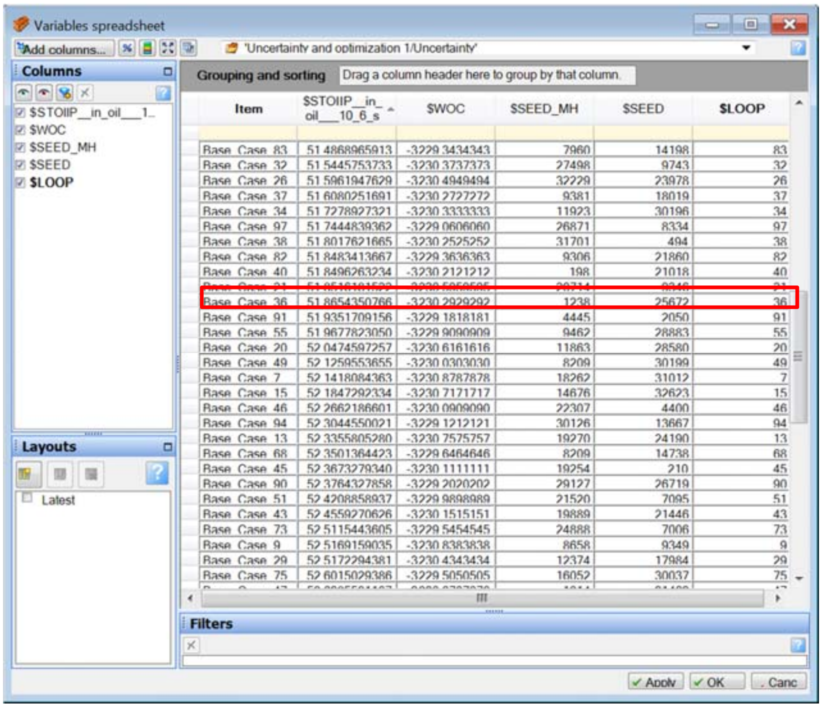
Uncertainties and optimization – P50 step 1

- **Use a table to determine P50 Model**
  - Select STOOIP (A)
  - Click on "Add "(B) and Close(C)
  - Click on column header to sort STOOIP



Uncertainties and optimization – P50 Step 2

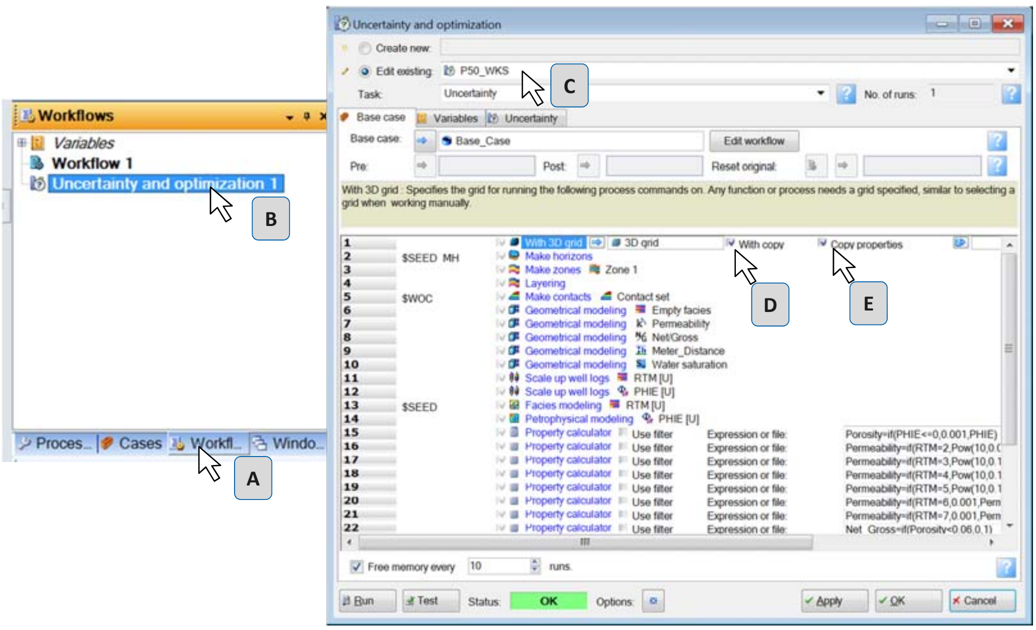
- **To display the results**
  - Find Volume for P50 = 51.9 E+6
  - Base Case 91 is the P50 model. This model will be used for the next step (upscaling)
  - Pick and write values for $WOC, $SEED_MH and $SEED



$WOC = -3229.18
$SEED = 2050
$SEED_MH = 4445

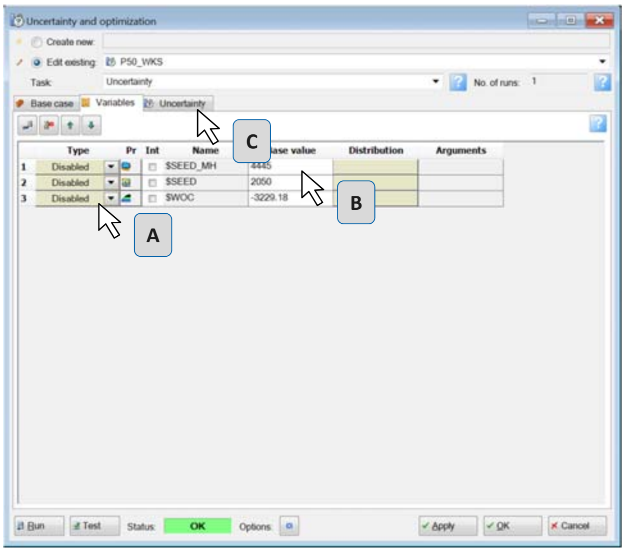
Uncertainties and optimization – P50 Step 3

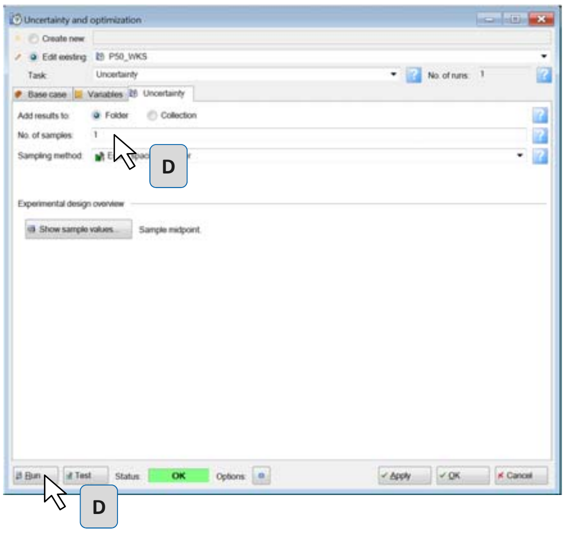
- **To display the results**
  - Select the Workflow index (A)
  - Open “Uncertainties and optimization 1” (B)
  - Select Create New, and type P50_WKF (C)
  - Select “With copy” and “Copy properties” (D) and (E)



Uncertainties and optimization – P50 Step 4

- **Sensitivity by variable**
  - Select Disable for $SEED_MH, $SEED and $WOC (A)
  - Select "Uncertaintie" (B)
  - Type 1 in no of sample (C)

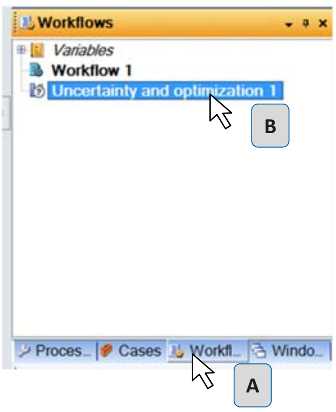


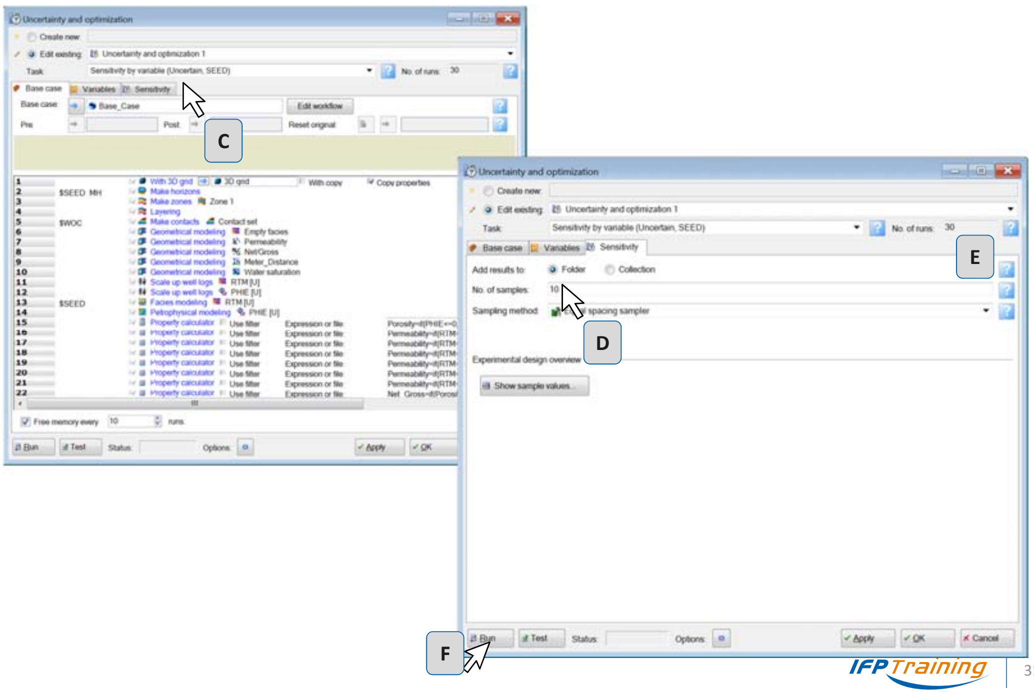


Sensitivity by variable

- **Sensitivity by variable**
  - In the Workflows window (A) select "Uncertainties and optimization" (B)
  - Select "sensitivity by variable" (C)
  - Choose the no. Of sample (D)
  - Be careful the "no of runs" will be automatically modified (E)
  - Run (F)

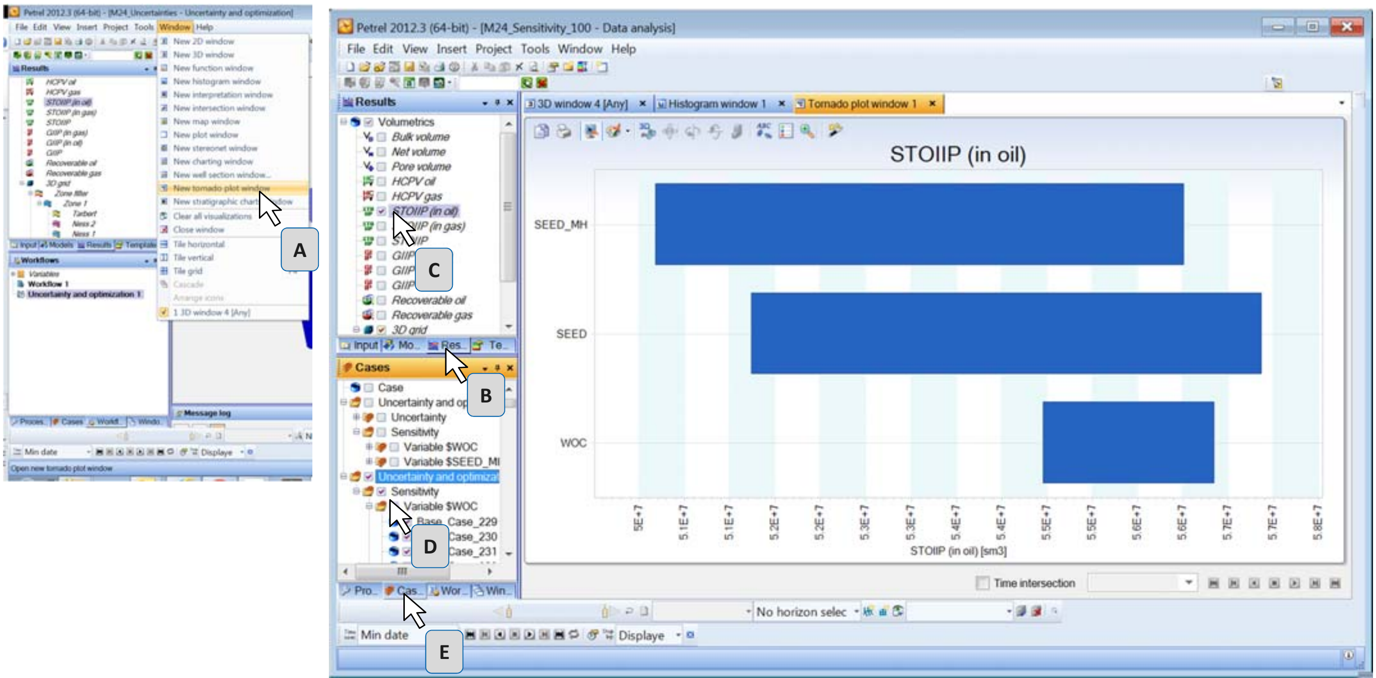
Time consuming!... several hours !

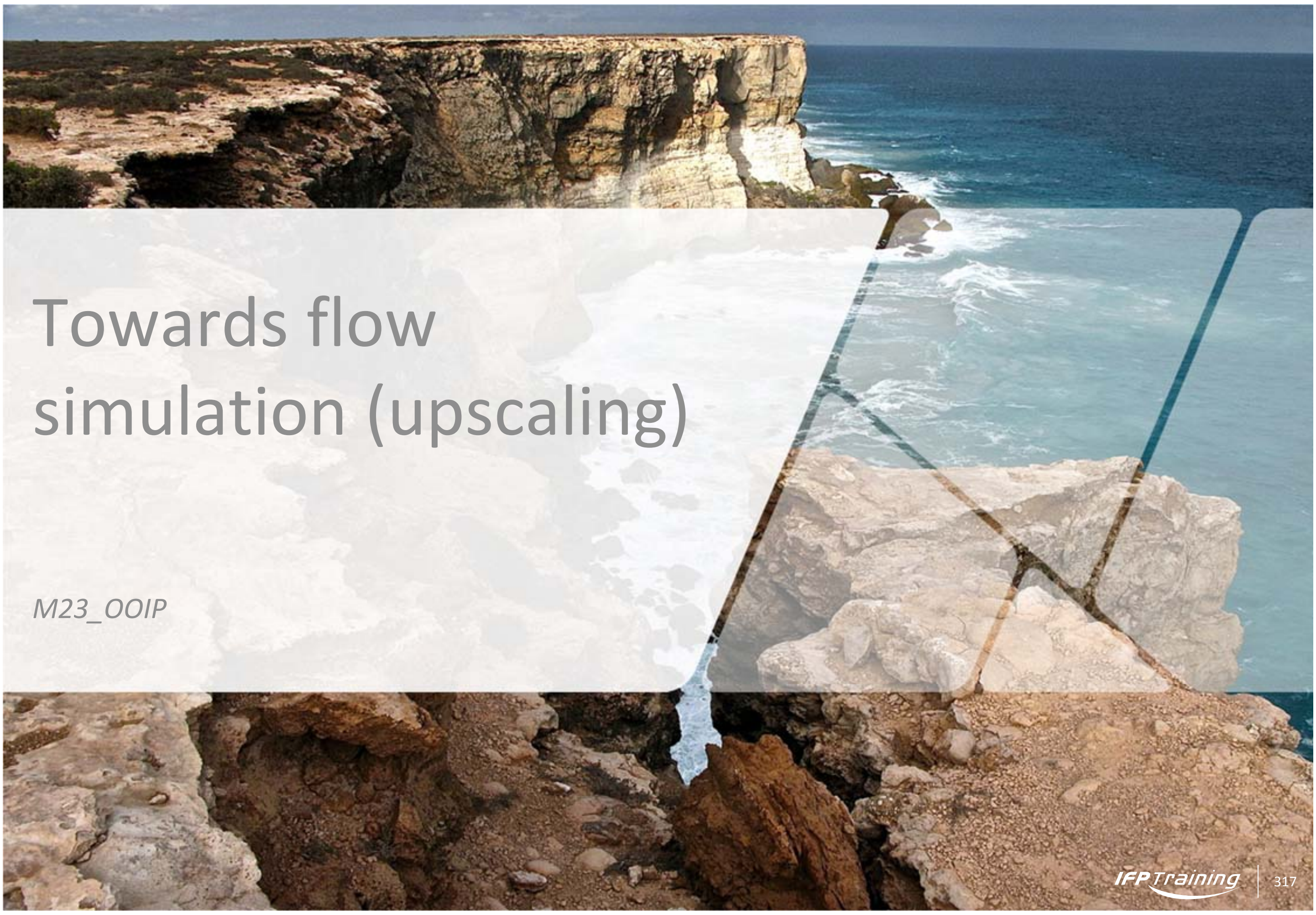




Sensitivity by variable – M28_Sensitivity_50

- **To display the results**
  - Open a new window named “New tornado plot window” (A)
  - Select the result (B) and STOOIP (C)
  - Select the case (D) and (E) created in the previous Step



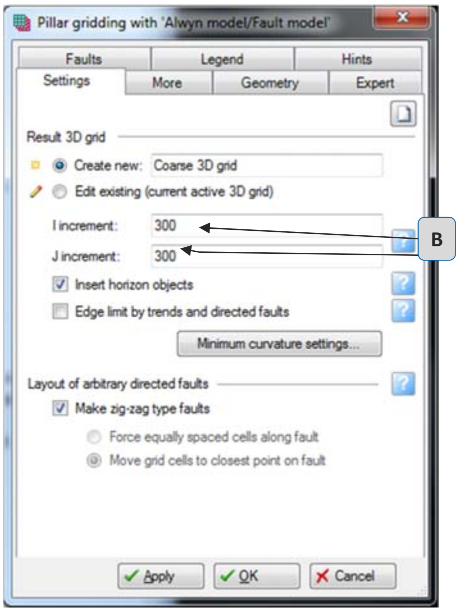


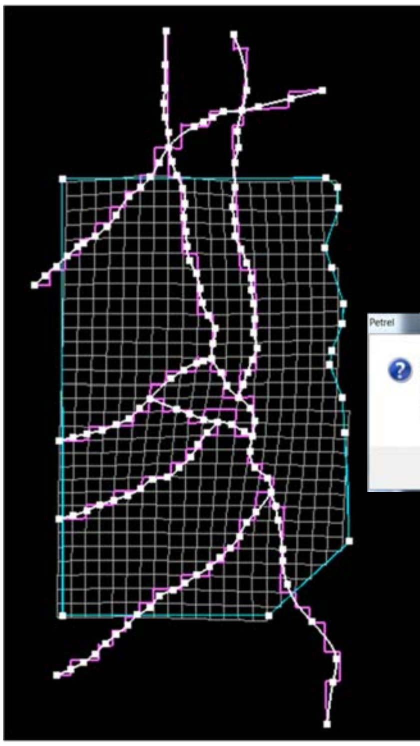
Towards flow simulation (upscaling)

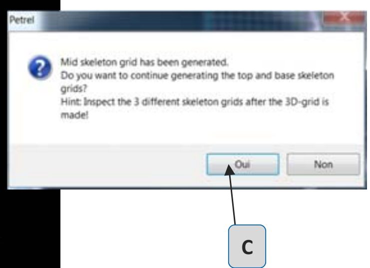
M23_OOIP

Upscale grid for fluid flow simulation – 1/4

- **Create a coarse grid**
  - Open a 2D window
  - Processes → Corner point gridding → Pillar gridding
  - Create a new grid and choose I/J increment (300x300 m) (B)
  - “Apply” + “OK” → Yes (top & base skeleton) - (C)

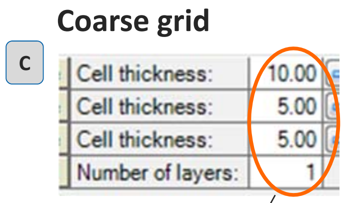


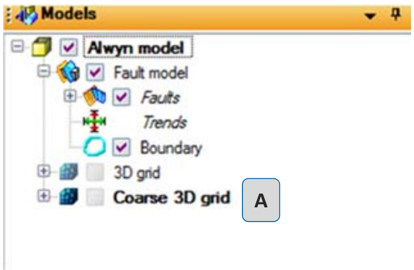


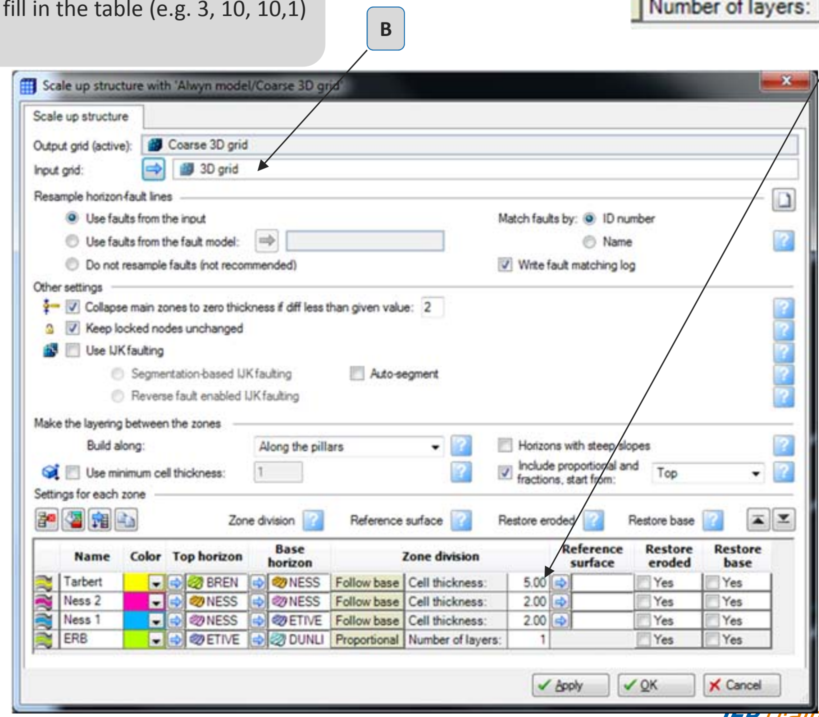


Upscale grid for fluid flow simulation – 2/4

- **Create coarse layering**
  - Select Coarse 3D grid (A)
  - “Processes” → Upscaling → Scale up structure
  - The “coarse” grid is fixed as output: select “fine” grid as input (B)
  - Use the coarse grid parameters to fill in the table (e.g. 3, 10, 10,1)
  - OK

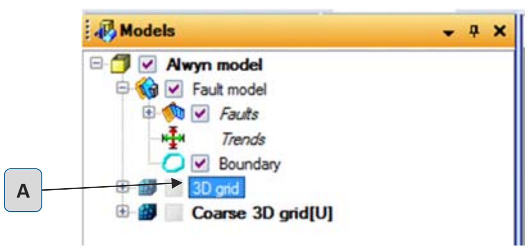


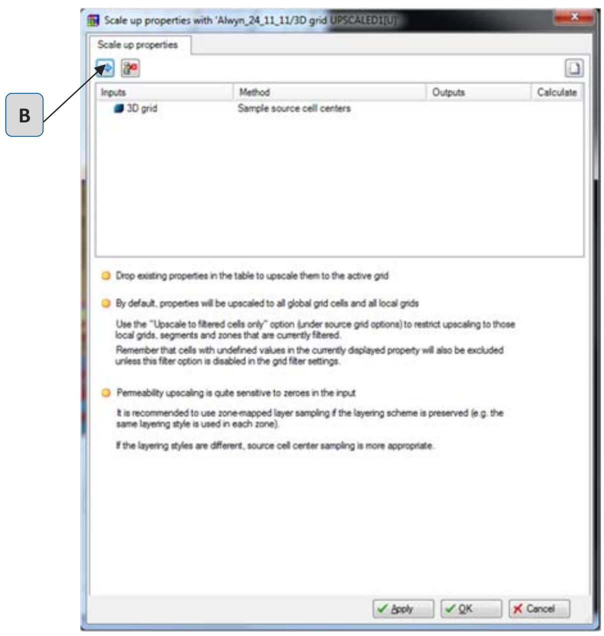




Upscale grid for fluid flow simulation – 3/4

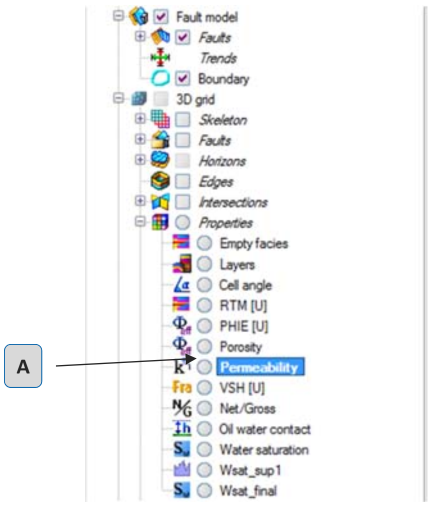
- **Upscale properties from a fine grid to a coarse grid for flow simulation**
  - Processes tab → Upscaling → Scale up properties
  - Select the fine grid you want to upscale properties (A)
  - (B) Use the arrow to input the fine grid in the Scale up properties Panel

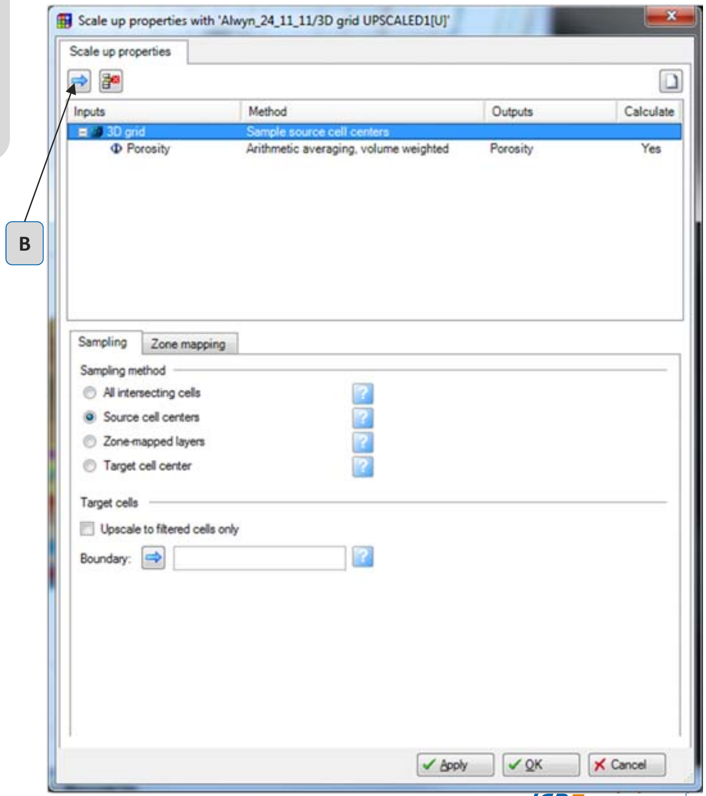




Upscale grid for fluid flow simulation – 3/4

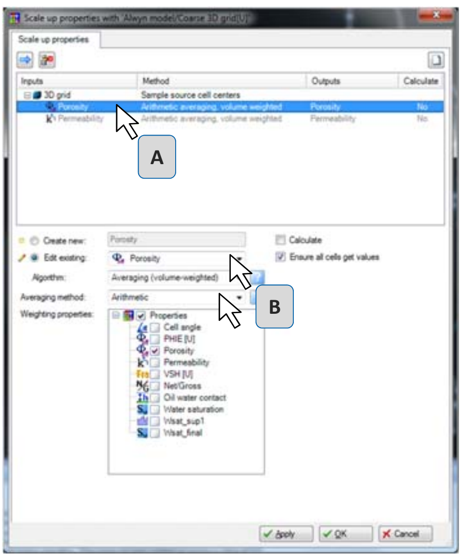
- **Upscale properties from a fine grid to a coarse grid for flow simulation**
  - Processes Panel → Scale up properties
  - Select the property you want to scale up (A)
  - (B) Use the arrow to input the Property in the Scale up properties Panel
  - Choose Porosity and Permeability for upscaling

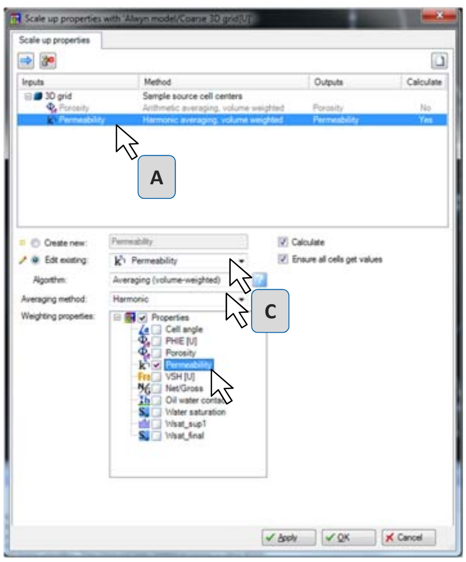




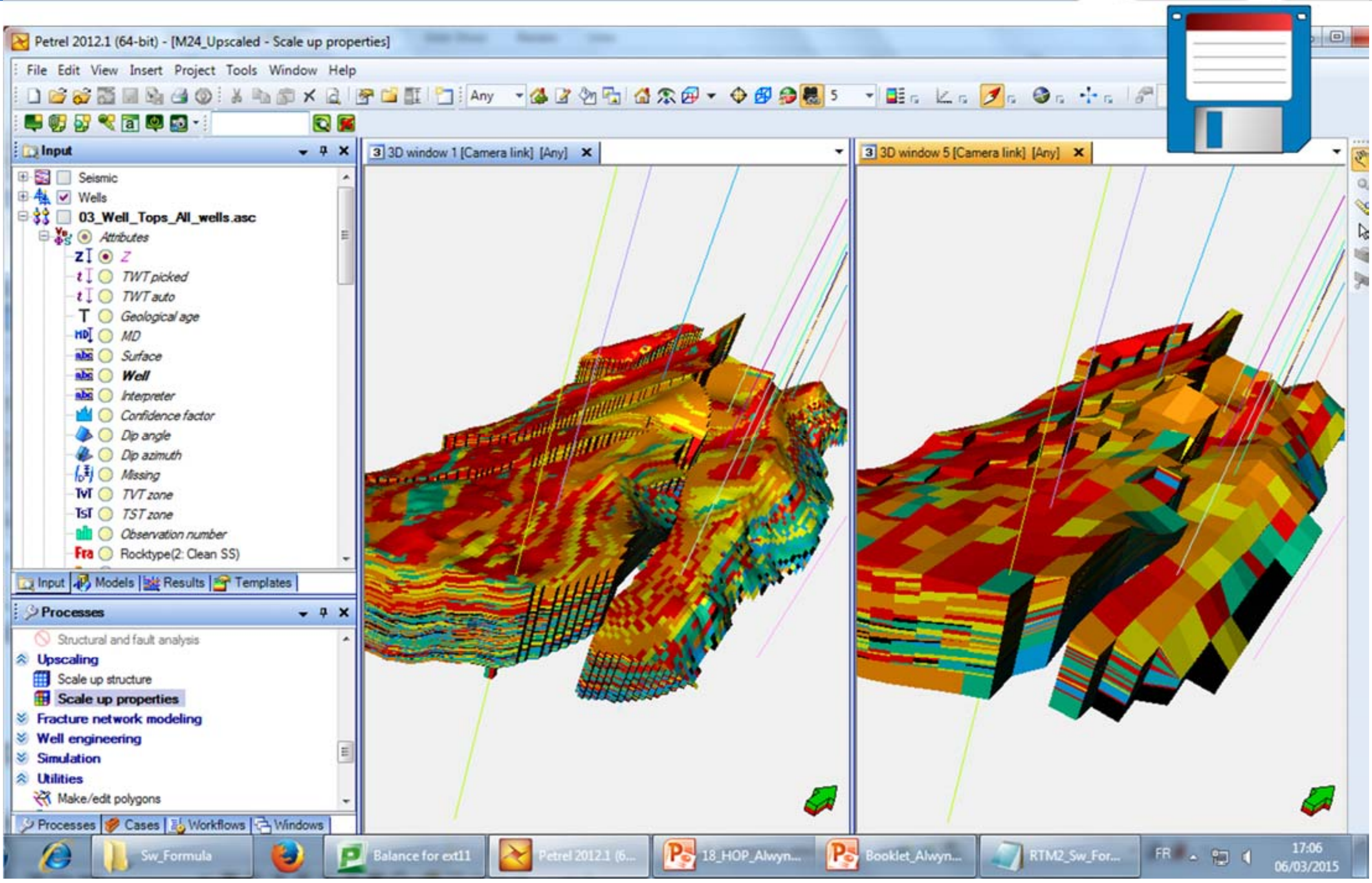
Upscale grid for fluid flow simulation – 4/4

- **Upscale properties from a fine grid to a coarse grid for flow simulation**
  1. Highlight property on Scale up properties Panel (A)
  2. Select Porosity and Algorithm (Arithmetic) - (B)
  3. Select Permeability Algorithm (Harmonic) (C)





Upscaled porosity model – M29_Upscaled



Appendices

Petrel toolbox

Hands-on handouts

Petrel toolbox

Petrel basic functions - Toolbox

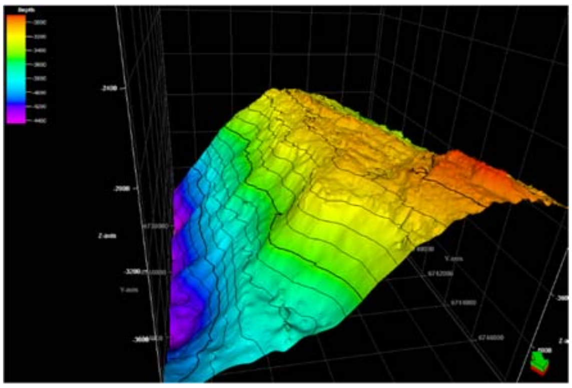
- **Display and color management**
  - Solid coloring option
  - Contour lines coloring option
  - Grid lines
  - Color scale
  - Restricting contours
  - Restricting colors
  - Restricting scale (grid blanking)
- **Map editing/printing**
- **Well section management**

Display & color management

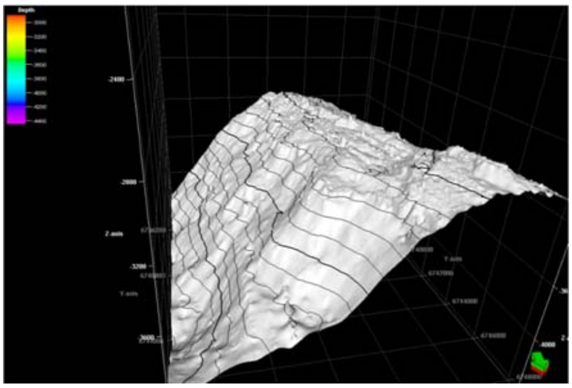
Solid coloring options

- **In settings**
  - Select the “Solid” option in the “Style” panel
  - Select “Z-value” to color the surface by depth
  - Select “Specified” to color with a selected color in “info” panel
  - “Black” or “White” can also be selected

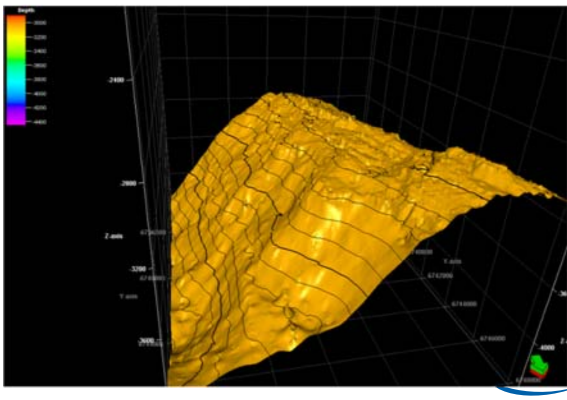
Color: Z-values



Color: White

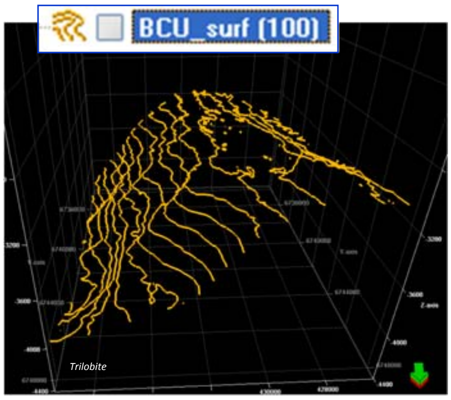


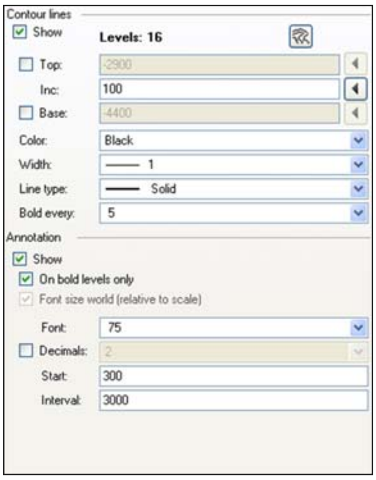
Color: Specified



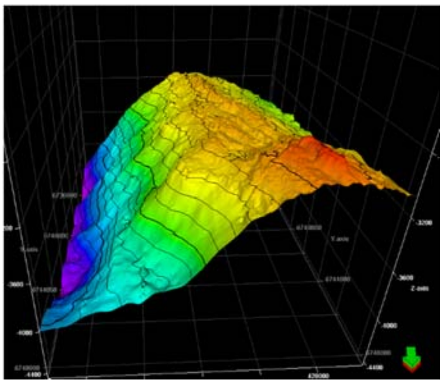
Contour lines coloring options

- **In settings**
  - Select the “Contours” option in the “Style” panel
  - You can select:
    - The contour type (solid, stippled, dotted, stipple-dot…)
    - The contour incrementation
    - The contour color (Black or white, specified, as Z-value)

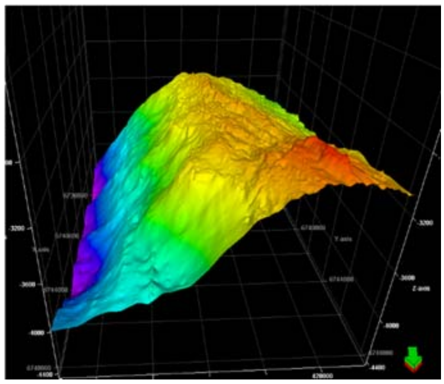




With contours

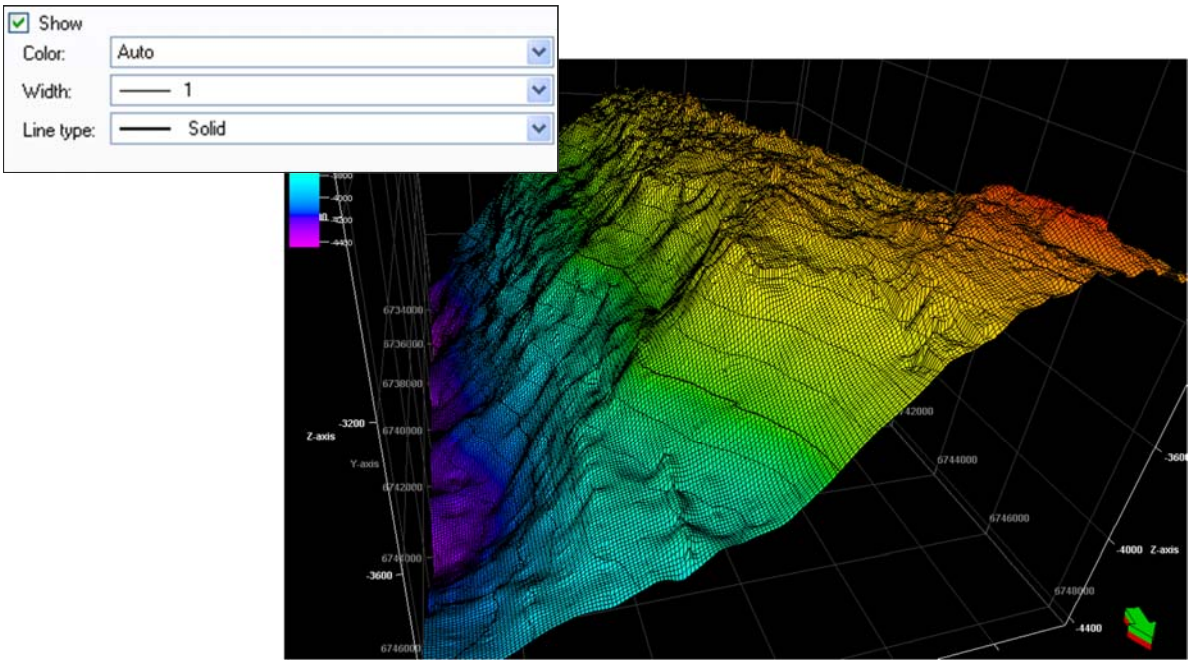


Without contours

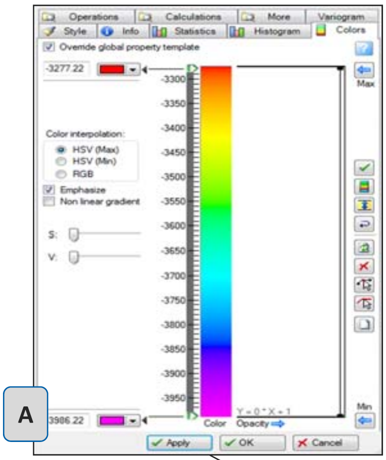


Grid lines

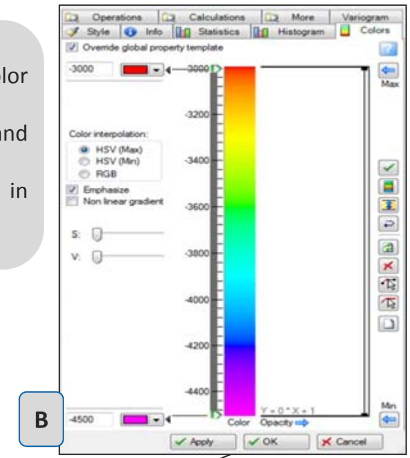
- **In settings**
  - Grid lines can be displayed by selecting the “Grid” option in the “Style” panel

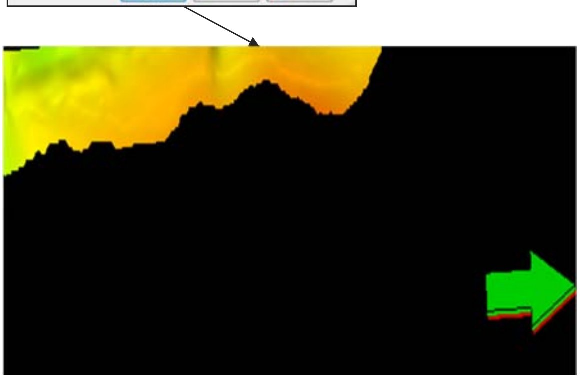


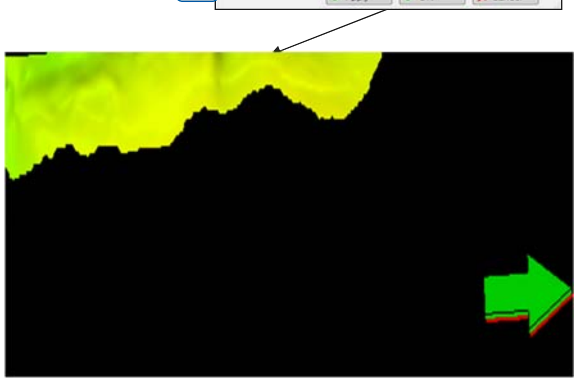
Color scale (1/2)



- **Change the color scale**
  - Right click on the surface and select “color table” to access the “settings” panel
  - Blue arrows automatically select the max and min values (A)
  - It is better to use the predefined scale in order to compare surfaces (B)
  - Enter values to modify the scale

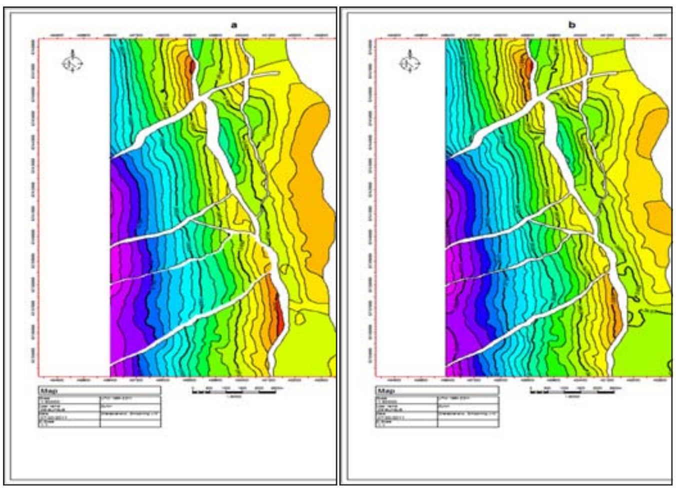




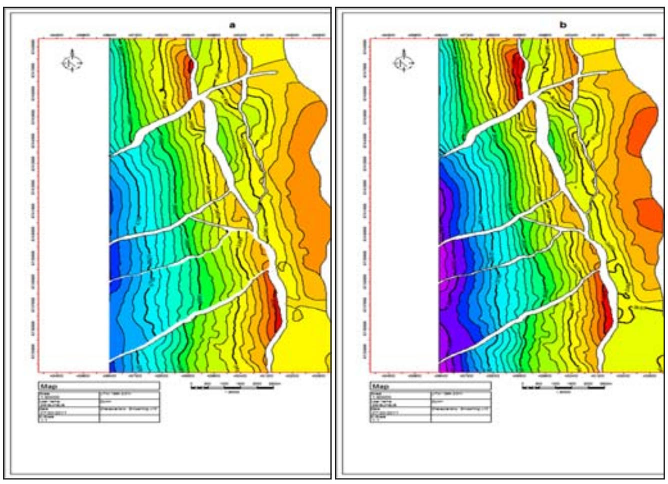


Color scale (2/2)

- In order to compare surfaces and maps, it is important to **keep the same display and color settings for all the surfaces**



Different map with different color settings

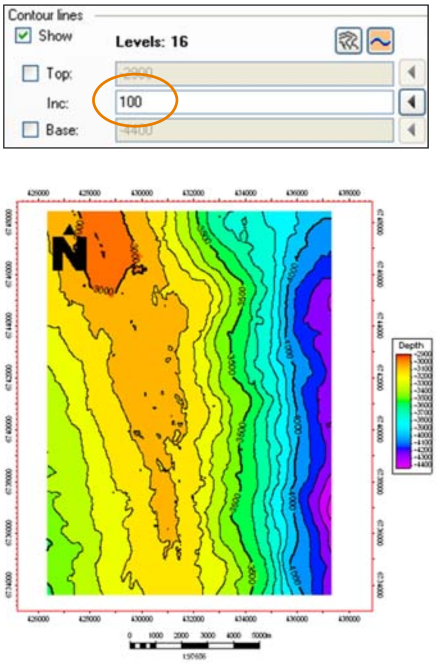


Different map with same color settings

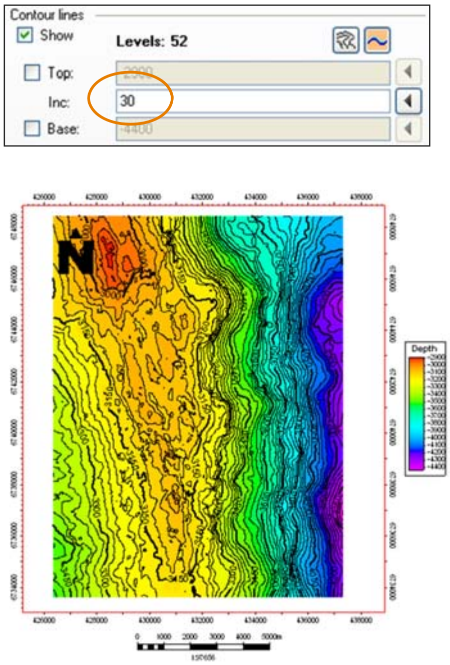
Restricting contours

- Select “Contour lines” in the “Settings” panel

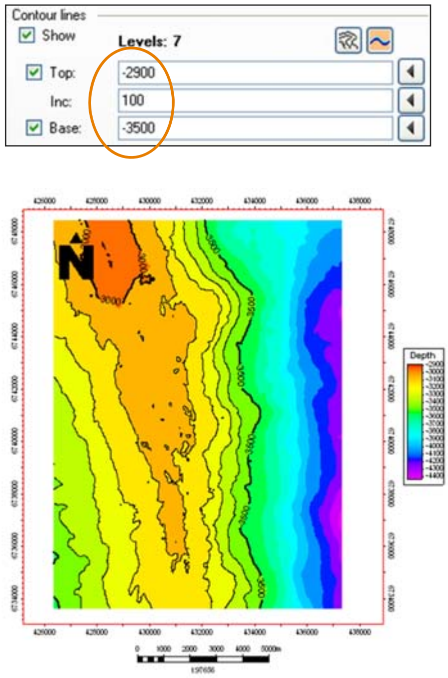
Full contouring high range



Full contouring low range



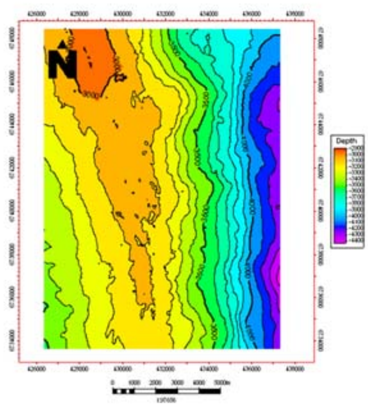
Restricted contour range



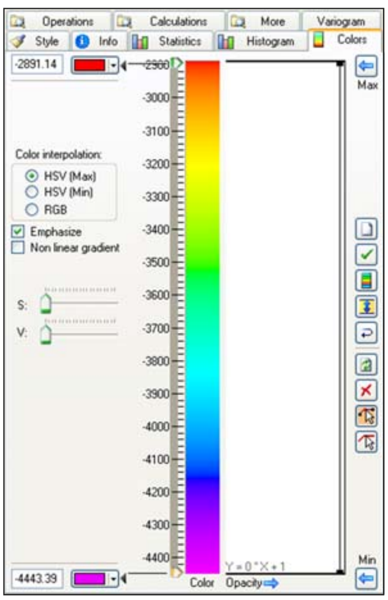
Restricting colors

- **In settings**
  - Select “Colors”
  - Insert the limit for colors and increase color smoothing in interval without interest

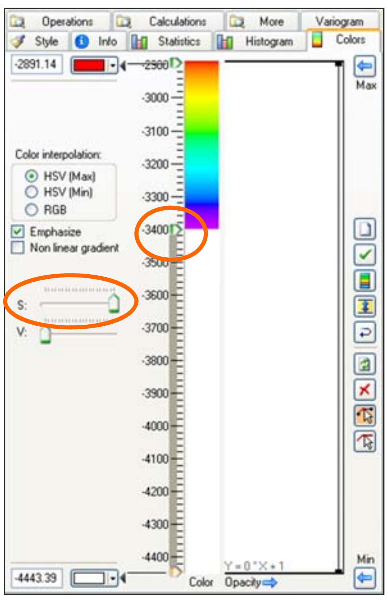
Full coloring results



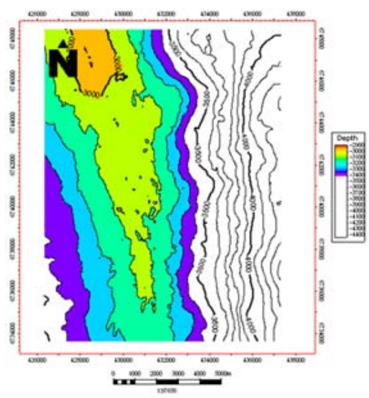
Full coloring settings



Restricted coloring settings

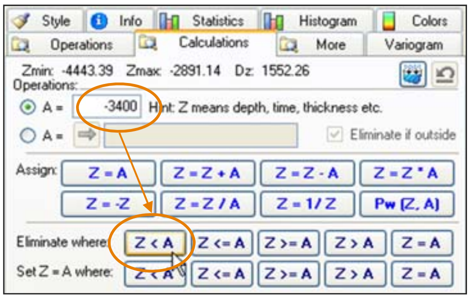


Restricted coloring settings

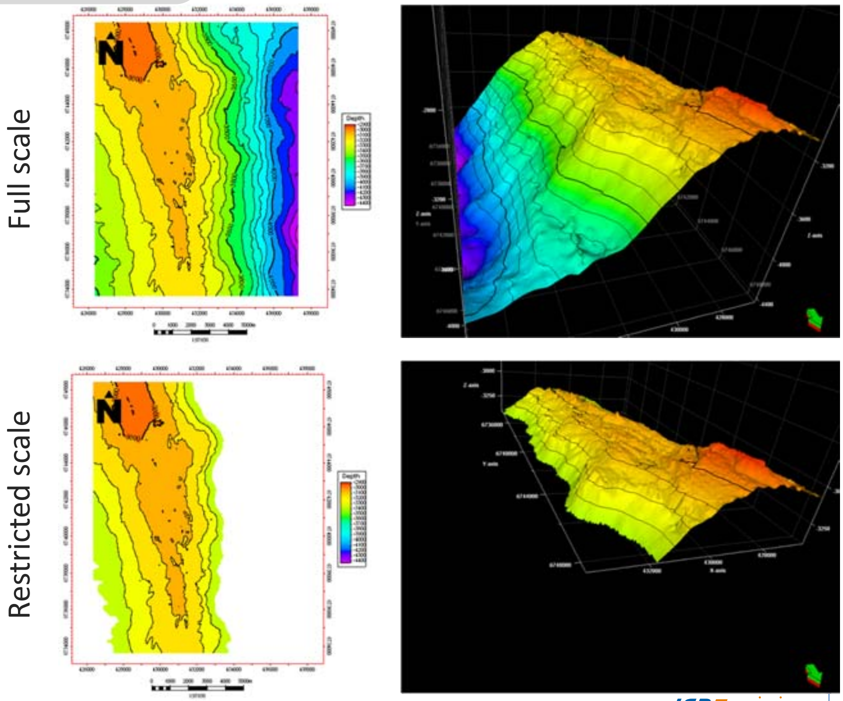


Restricting scale (grid blanking)

- **In settings**
  - Select “Calculations”
  - Assign a value as boundary to cut the grid (here: – 3400 m)
  - Select “Eliminate where Z<A”
  - The grid below – 3400 m is blanked

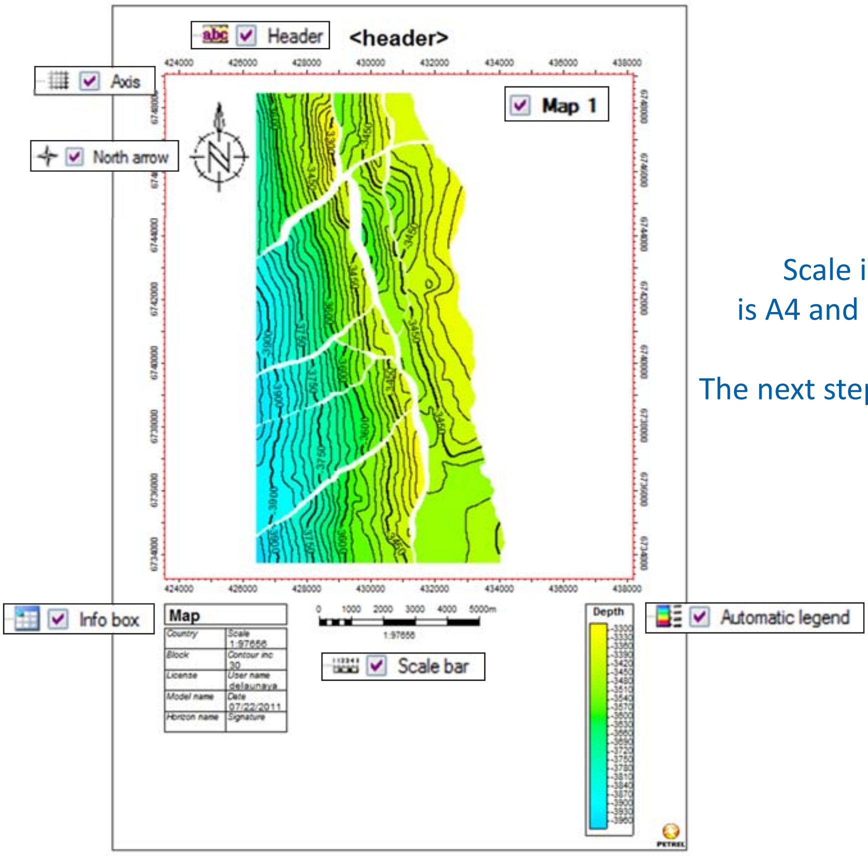


A single “UNDO” only is available on this process.
→ Perform this workflow on a copy of the original surface



Map editing/plotting

Initial “Map window”

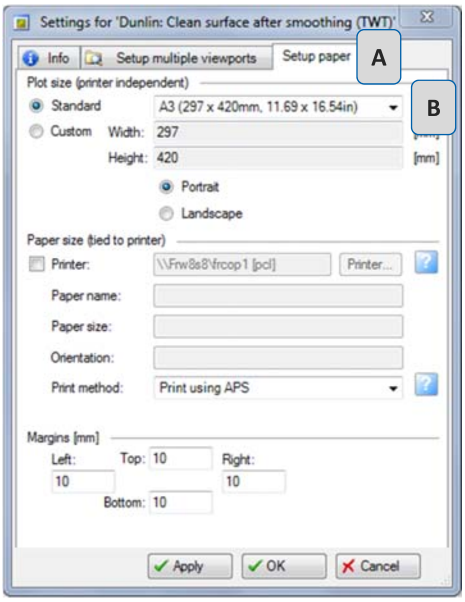


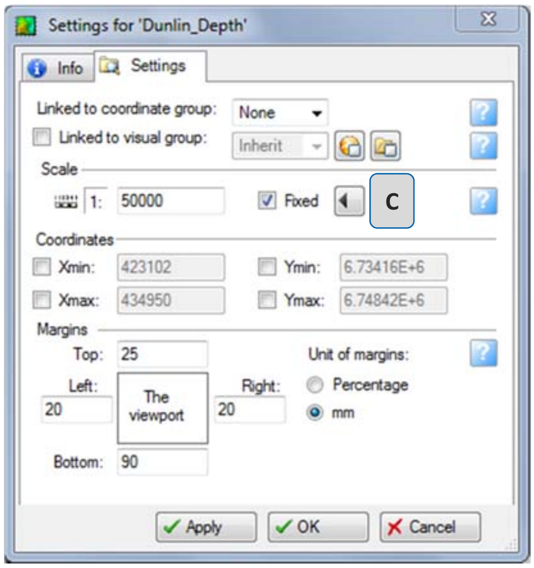
Scale is not round: paper format is A4 and does not allow a bigger scale.

The next steps will help with the proper map window settings.

Map editing (1/2)

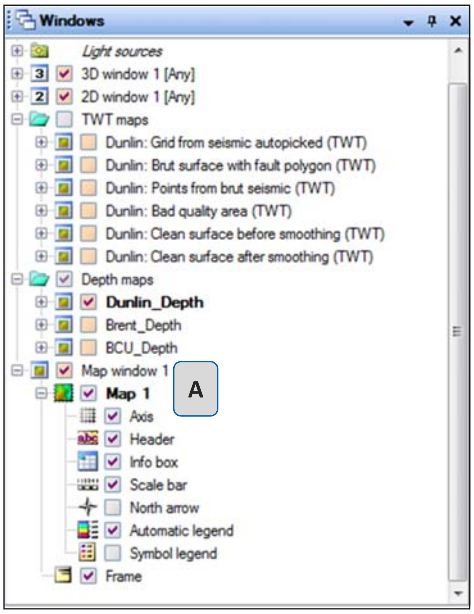
- Set up the paper format (A3, A4…) in which the map fits depending on the scale used
  - Double click on *Map window* and select "Setup paper" (A)
  - Select right format (B)
- **Set up the scale (1/50000)**
  - Double click on and select "Settings"
  - Tick fixed and set scale at 1:50000 (C)

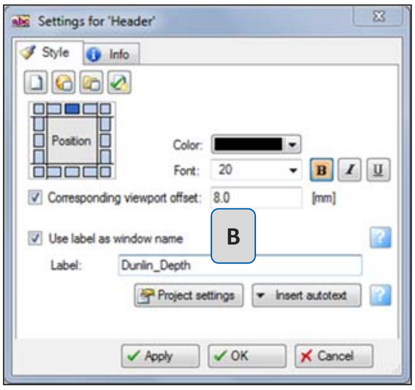


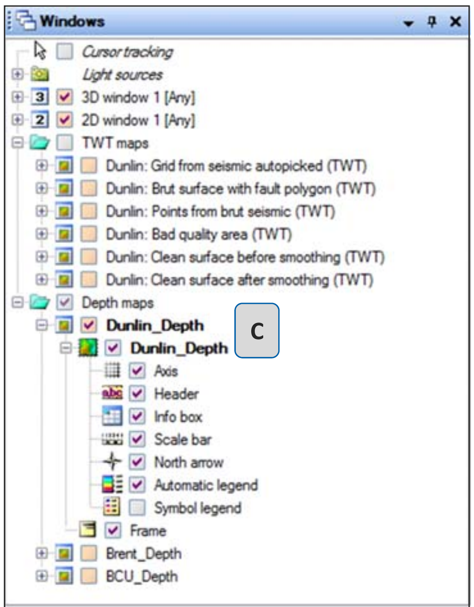


Map editing (2/2)

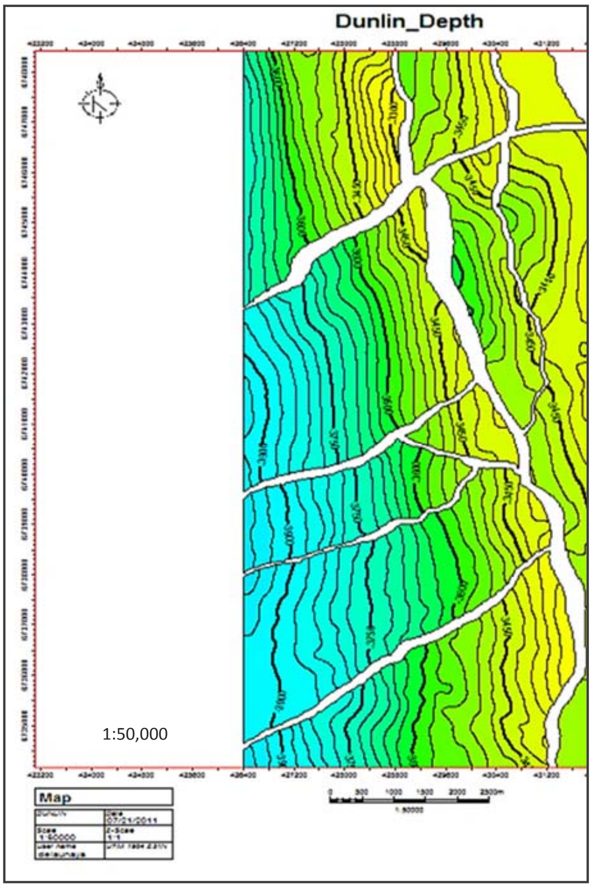
- **Set up the Map window**
  - Select "New map window" in *Window*
  - Extend "Map window 1" and "Map 1" (A)
    - By double clicking on any option you access the settings
  - In *Header* enter "map name" as *Label* and select "Use label as window name" (B)
  - The name appears as a header and window name (C)







Final “Map window”



- **Changes:**
  - Map name as a header
  - Paper format is A3
  - Scale is 1:50,000
  - Info box is smaller

Surface and map editing

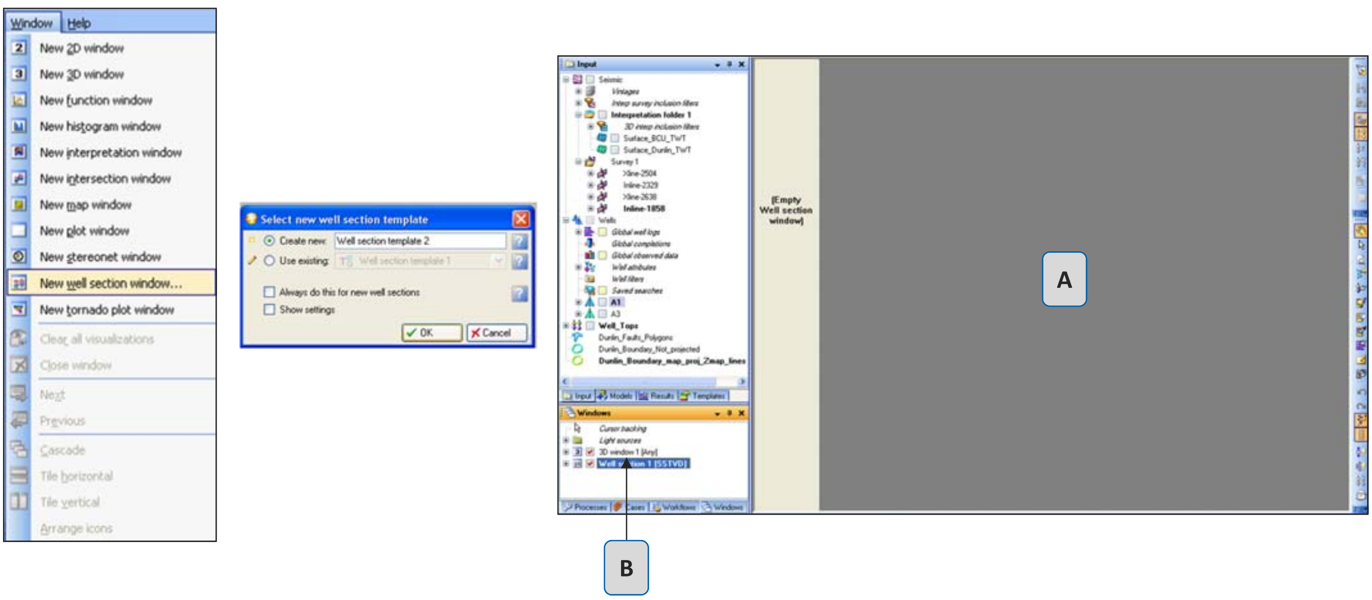
- **Set parameters that will allow to compare maps and surfaces**
  - Set scale and paper format
  - Set color scale
  - Use the same increments for all the surfaces
    - If too large: loss of accuracy
    - If too tiny: all the operations take much longer

Well section

Correlation between wells

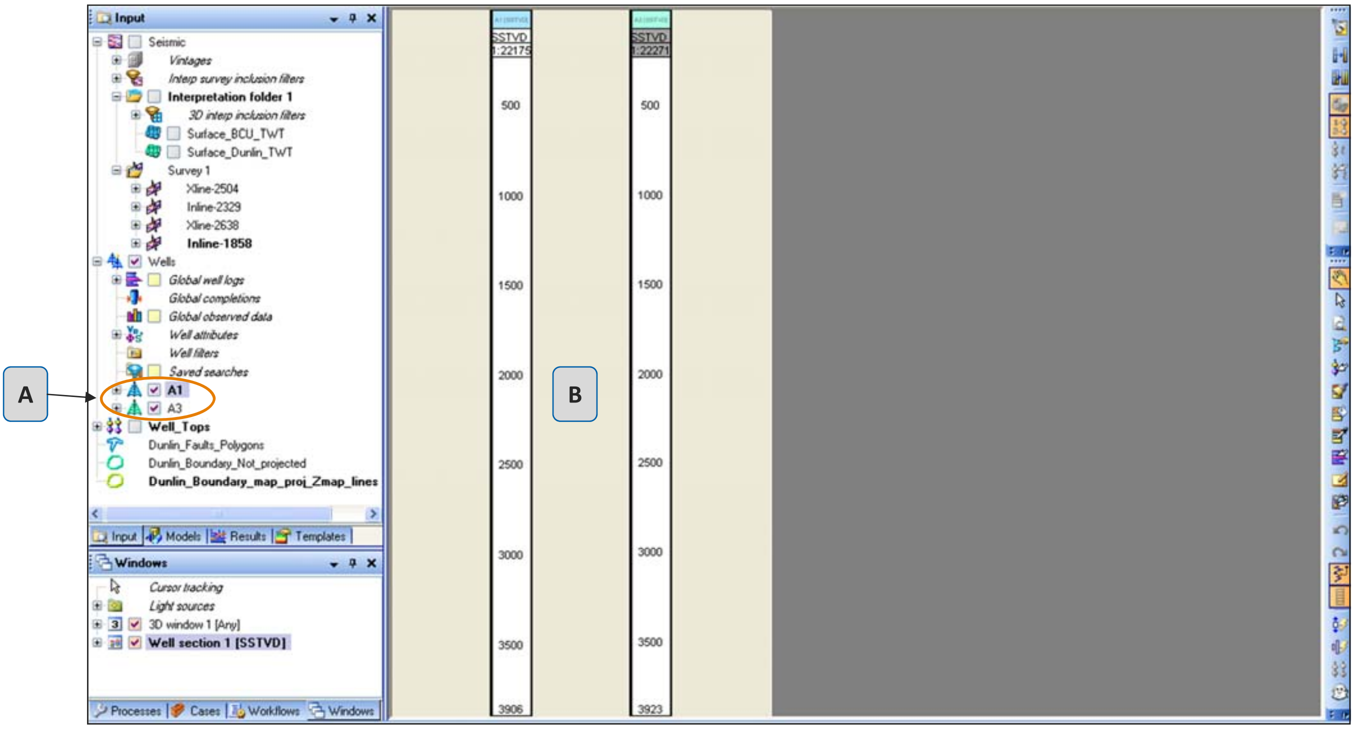
Create a well section window

- **Select “New well section window” on “window” Menu**
  - The display window is empty (A)
  - A well section appears in the “window” panel (B)



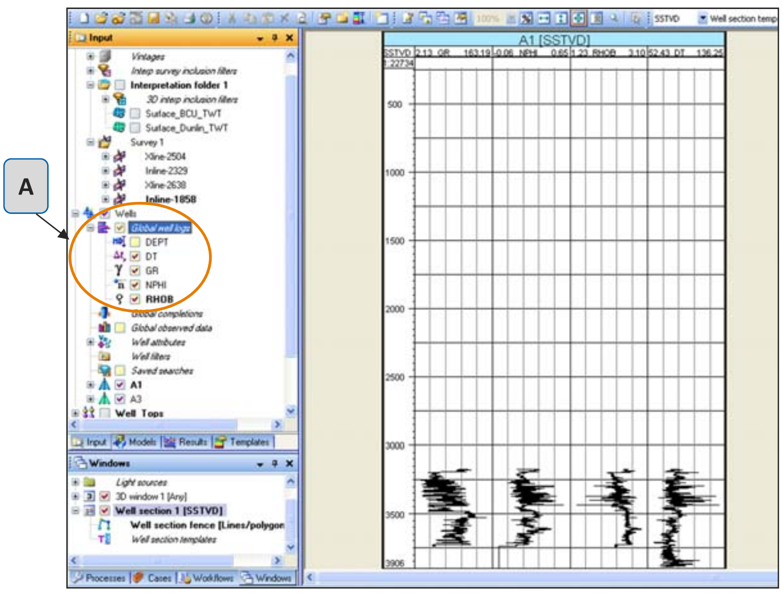
Integrate well trajectories

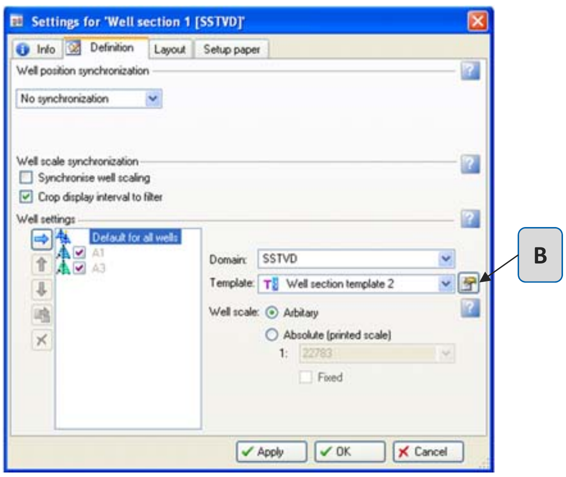
- Select wells in the "input" panel (A)
- Wells appear in the display window (B)



Integrate well logs (1/2)

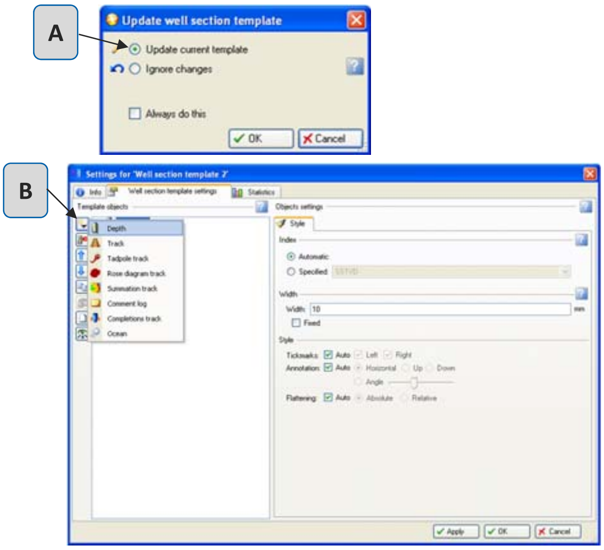
- Select in the input panel (*Global well logs*) the logs to display in the well section (A)
- Double click on "*Well section 1 window*" and select the icon "*Show well section template settings*" (B)

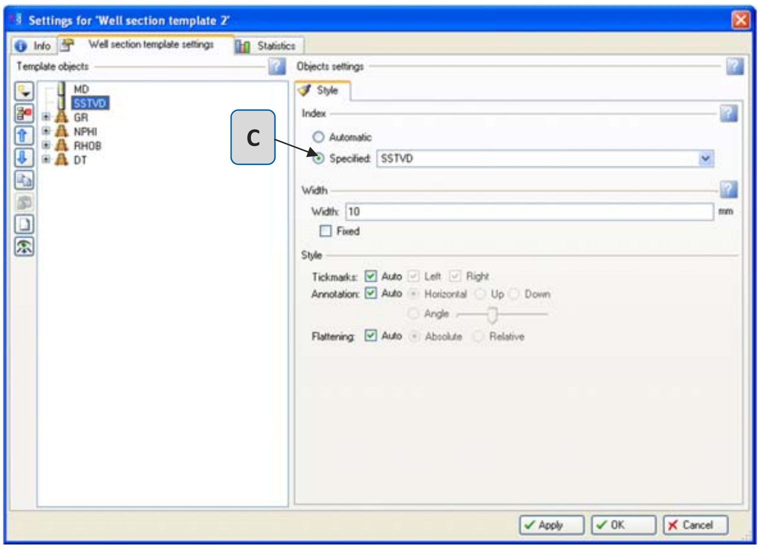




Integrate well logs (2/2)

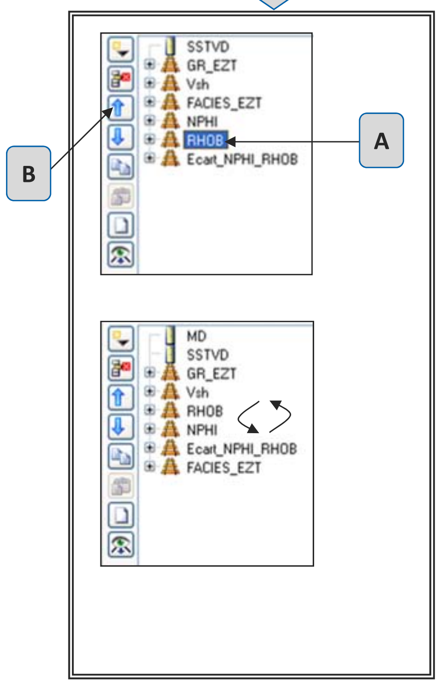
- Select “*Update current template*” (A)
- Select the icon “*Add new object*” (B)
- Insert first a new depth track, and select on the right window the depth scale (MD and SSTVD) (C)
- Same operation with the other tracks

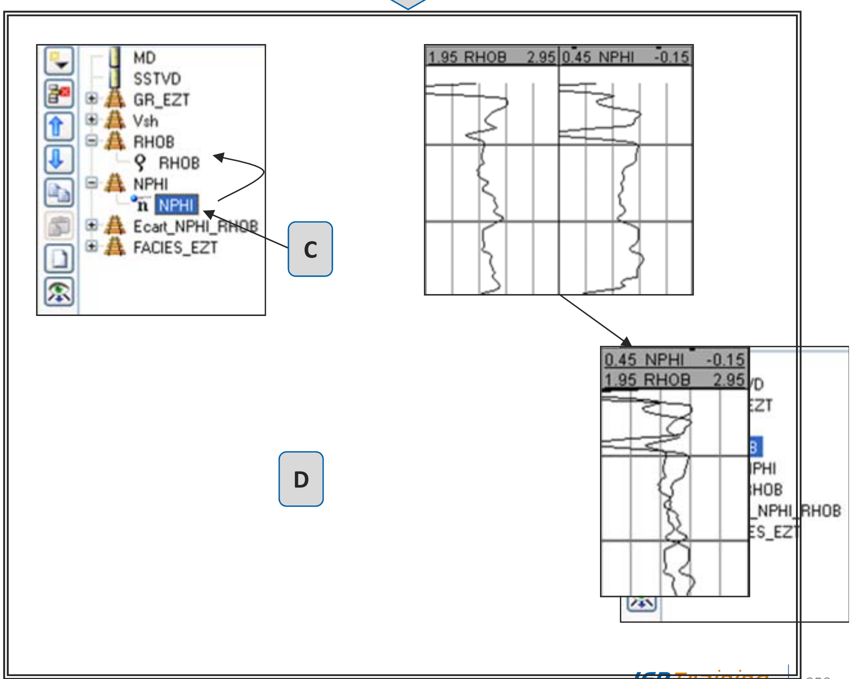




Display logs

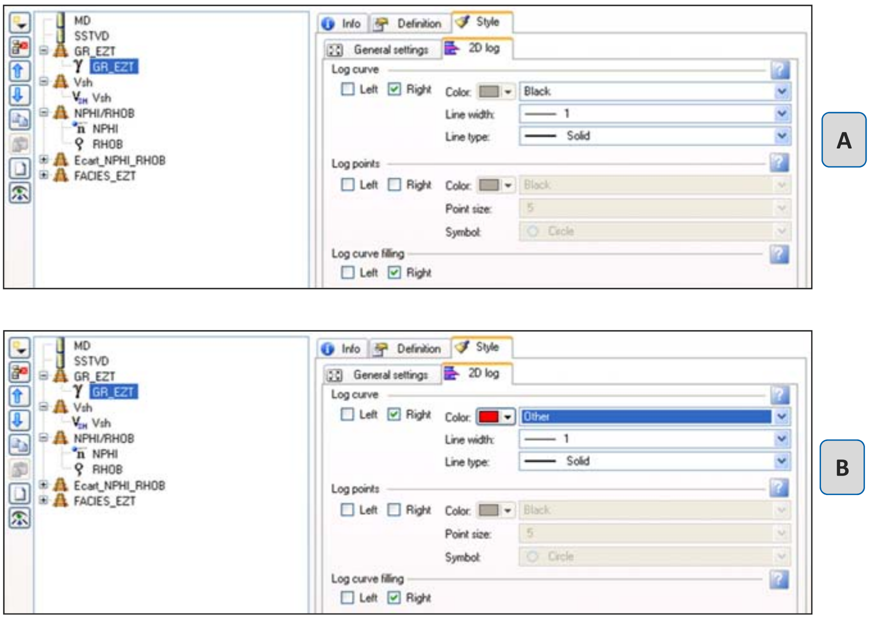
- Move logs order from “Settings for the well section templates”
  - Select the logs to move (A) and use up or down arrows to move into other log (B)
- Merge two logs in the same track from “Settings for the well section templates”
  - Select the log to move (C) and use up or down arrows to move into other log (D)

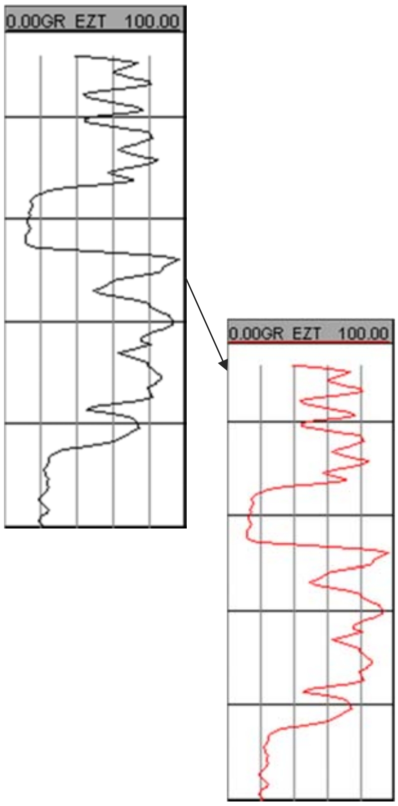




Color options (1/3)

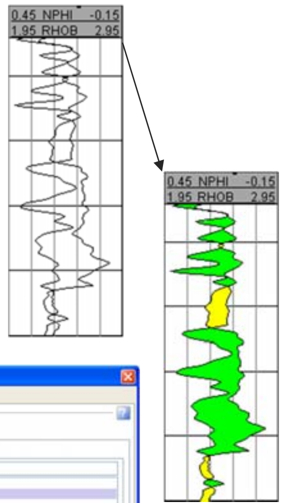
- **Simple color underlying**
  - Select log in the “Settings for Well section template” and select “Style” and “2D log” panels (A)
  - Select “Other” and change the color in the “Log curve” options (B)

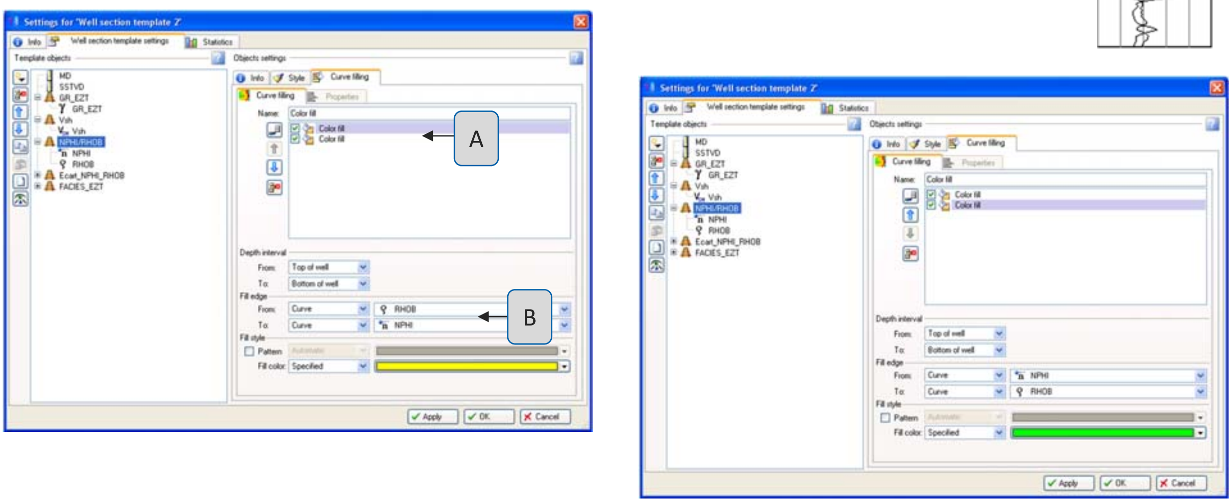




Color options (2/3)

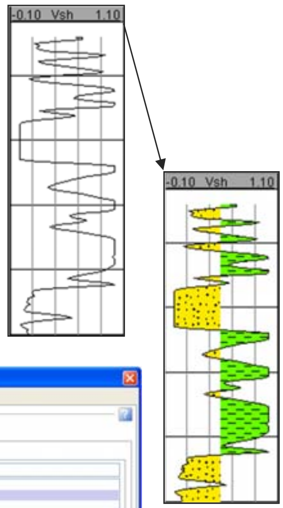
- **Color filling between 2 curves**
  - Select the track title in ”Settings for well section template”
  - Select the “Curve filling” panel
  - Add two lines (A) and select the curves in the “Fill edge” (B)
  - Select the colors (the example shows a standard choice)

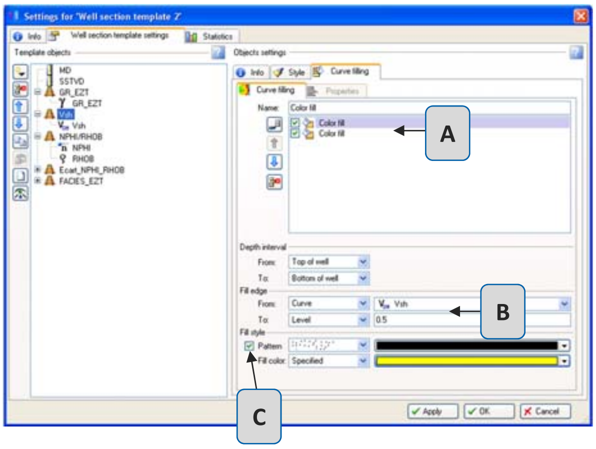


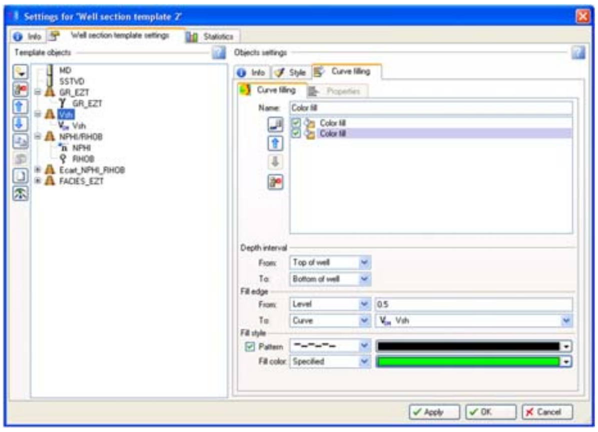


Color options (3/3)

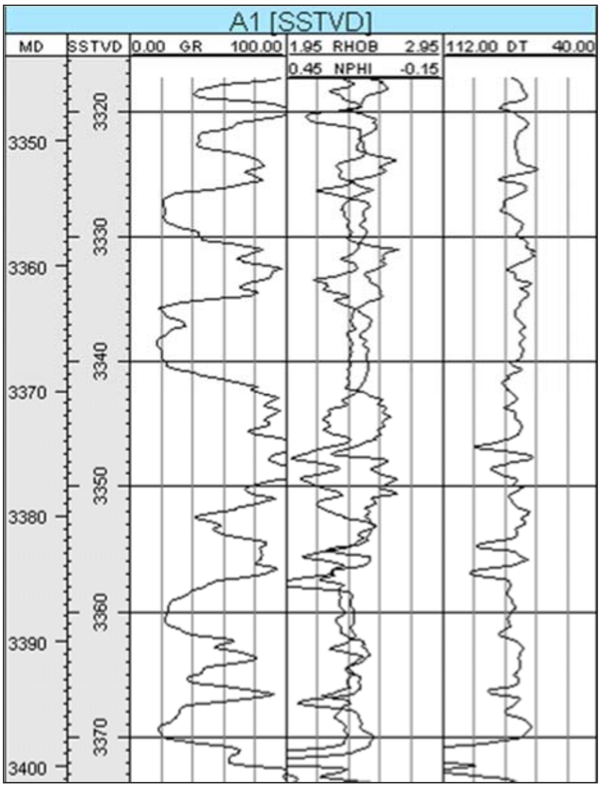
- **Color filling with cut-off**
  - Select the track title in “Settings for well section template”
  - Select the “Curve filling” panel
  - Add two lines (A) and select “level” and “curve” in “Fill edge” (B)
  - Enter the cut-off values (here 0.5)
  - You can also select a pattern in “Fill style” (C)

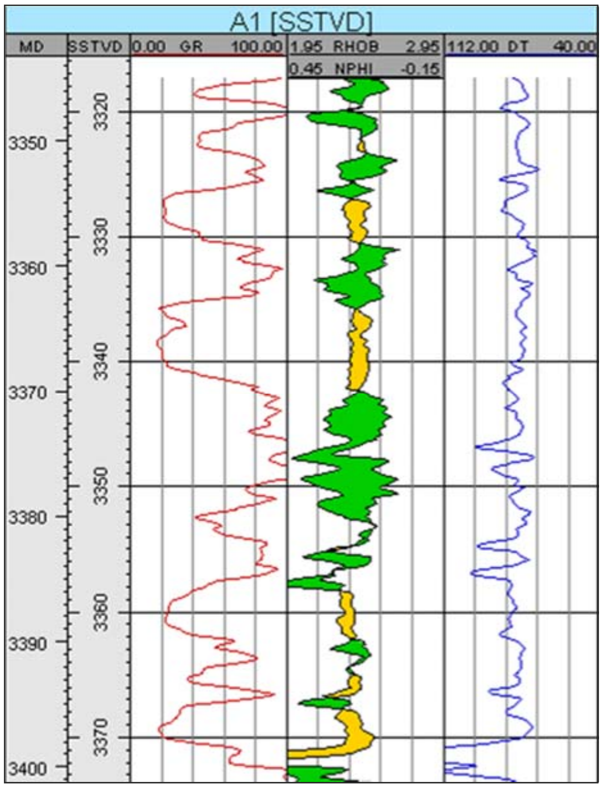




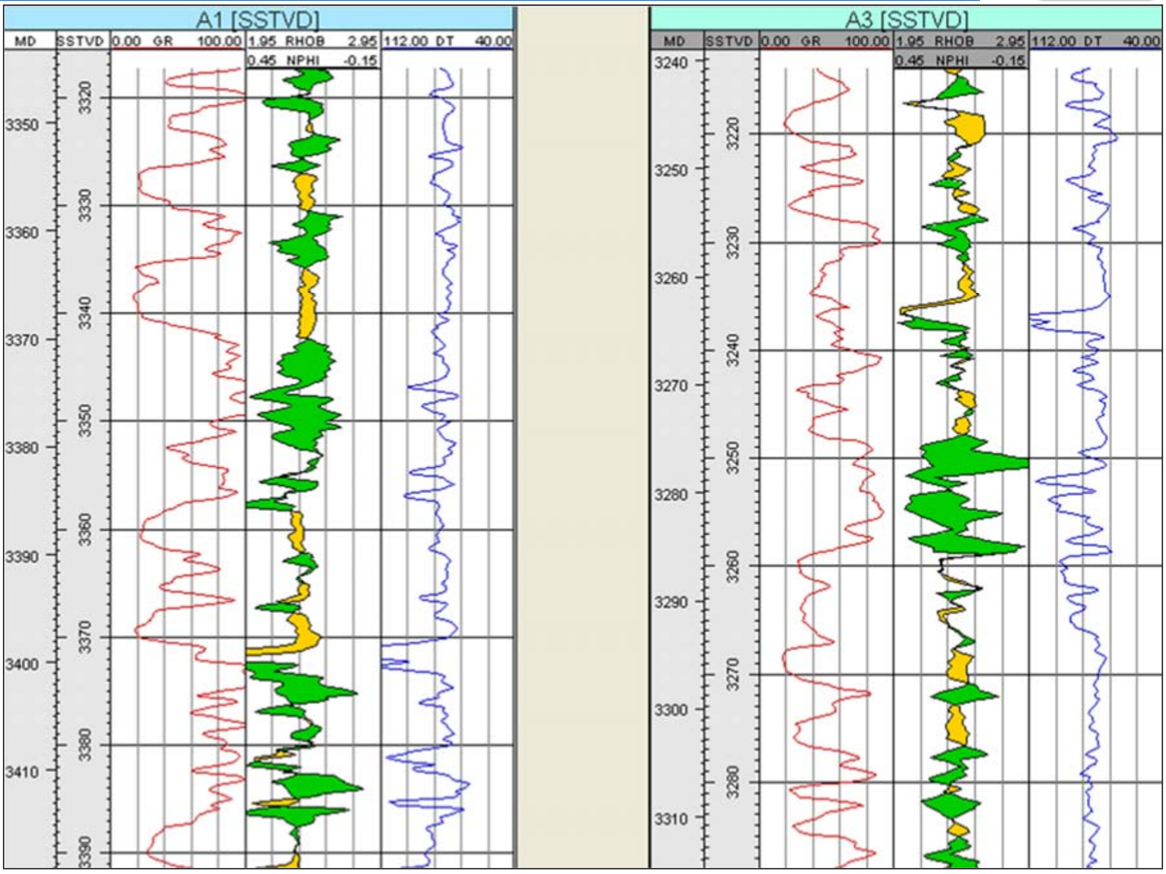


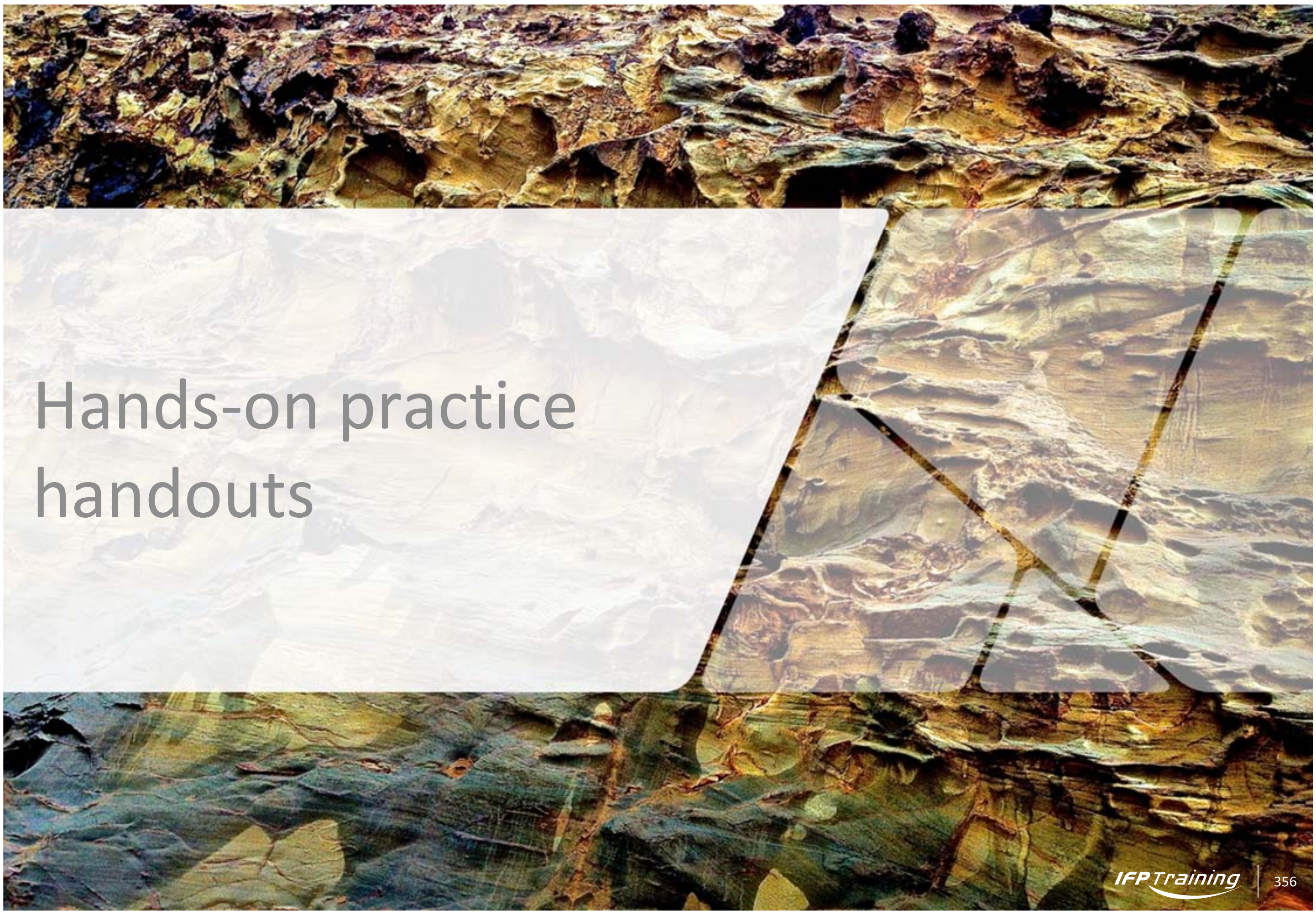
Display the results (1/2)





Display the results (2/2)





HOP summary

- **Alwyn case study**
  - Hands-on handouts
    - Structural characterization - [HOP #1]
    - Stratigraphic characterization - [HOP #2]
    - Sedimentological characterization - [HOP #3]

→ *Use the figures printed on Tabloid (A3) format documents*